



**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**  
**Washington, DC 20460**

**AUTHENTICATION**

I, Jennifer Noonan Edmonds, attest that I am the Director, Policy Analysis and Communications, Office of Air Quality Planning and Standards, Office of Air and Radiation of the United States Environmental Protection Agency (EPA or Agency) and that the attached documents are true, correct, and compared copies of the file copies in my legal custody, consisting of:

June 2, 1998, letter to David Markwordt, NESHAP for Ethylene Oxide Commercial Sterilization and Fumigation Operations (13 pages)

June 9, 1998, letter to David Markwordt, Typical Backvent Emissions and Concentration Estimates (4 pages)

April 28, 1986, Memorandum to David Markwordt, Short-Term Emission Parameters for Ethylene Oxide Emissions from a Model Ethylene Oxide Sterilization Facility (12 pages)

February 7, 1991, Memorandum to David Markwordt, Costing of Control Alternatives for Rear Chamber Exhaust Emissions (59 pages)

June 15, 1998, letter to David Markwordt, Correction to Information on Typical Backvent Emissions Estimates (3 pages)

**Subscribed under the penalty of perjury on this 14th day of July, 2023.**

**JENNIFER EDMONDS**

Digitally signed by JENNIFER EDMONDS

Date: 2023.07.14 17:11:55 -04'00'

**Jennifer Noonan Edmonds, Director**  
**Policy Analysis and Communications**  
**Office of Air Quality Planning and Standards**  
**Office of Air and Radiation**

**CERTIFICATION OF TRUE COPY**

I, Jennifer Clark, certify that I am the Associate General Counsel, General Law Office, Office of General Counsel, of the United States Environmental Protection Agency; that I am the designee of the General Counsel for the purpose of executing certifications under 40 C.F.R. sec. 2.406; that I have duties in Washington, District of Columbia; and that the official whose signature appears above has legal custody pursuant to 40 C.F.R. sec. 2.406 of the original documents, copies of which are attached, as witnessed by my signature and the official seal of the United States Environmental Protection Agency.

**Jennifer Clark**  
**Associate General Counsel**  
**General Law Office**  
**Office of General Counsel**

K Steilen  
13 Pages

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**Ethylene Oxide Sterilization Association, Inc.**

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ite 500, 1815 H Street, N.W. • Washington, D.C. 20006-3604 • U.S.A.

June 2, 1998

Mr. David Markwordt  
Policy, Planning and Standards Division  
Office of Air Quality Planning and Standards  
U.S. Environmental Protection Agency  
8th Floor  
411 Chapel Hill Street  
Durham, NC 27701

Re: NESHP for Ethylene Oxide Commercial Sterilization  
and Fumigation Operations

Dear Mr. Markwordt:

The purpose of this letter is to provide input to the U.S. Environmental Protection Agency (EPA) on the National Emissions Standard of Hazardous Air Pollutants for Ethylene Oxide Commercial Sterilization and Fumigation Operations (EtO NESHP). As the Secretary of the Ethylene Oxide Sterilization Association's (EOSA)\* Safety Subcommittee and the Environmental, Health and Safety Director of Griffith Micro Science, I am authorized to state that the following is representative of the positions of both EOSA and Griffith Micro Science. In addition, having reviewed this response with the Environmental, Safety and Health task group of the Health Industries Manufacturers Association (HIMA), I believe that the information presented is representative of most of the ethylene oxide sterilization industry.

The EtO NESHP has been subject to much review in the past year. We appreciate your assistance in helping the ethylene oxide commercial sterilization industry address the recent safety concerns associated with the integration and operation of the

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\* The Ethylene Oxide Sterilization Association (EOSA) is a trade association of those having an interest in ethylene oxide (EtO) used for sterilization purposes. The Association's purposes are to foster and disseminate truthful communications with regard to the safe use of EtO, to promote reasonable regulations, and to proactively address issues of interest to the membership. EOSA members have interests as diverse as: sterilant suppliers, sterilizer equipment manufacturers, sterilization facility operators, medical device manufacturers, medical packaging, laboratory service providers, analytical instrumentation, emissions control, and healthcare worker protection.

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equipment needed to meet the requirements of this regulation. While industry is still in the process of thoroughly reviewing these safety issues and identifying the safeguards necessary to prevent further incidents, it now believes that a portion of the EtO NESHAP needs to be further delayed to ensure that most sterilizers can comply with the NESHAP without compromising the safety of operations. In addition, some modification to the regulation would greatly assist industry to address the safety concerns without compromising the regulation's pollution control benefits for the environment.

To help you better understand industry's position, we are providing herewith the commercial sterilization industry's perspective on the background of the EtO NESHAP, emission control alternatives, safety incidents and concerns, suggested NESHAP modifications, and a listing of information that industry will provide to EPA in the near future.

#### EtO NESHAP Background

Following, are key dates and events relevant to the EtO NESHAP:

- o In 1984, OSHA regulated employee EtO exposure to a level of 1 ppm averaged over an 8-hour work shift. To comply with this regulation almost all sterilizers installed chamber exhaust vents (also known as "backvents") on sterilization chambers to minimize worker exposure.
- o In 1986 the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA, colloquially known as the "Superfund") was amended by the Superfund Amendments and Reauthorization Act to add a new Title III, the Emergency Planning and Community Right-To-Know Act of 1986 (EPCRA). It is Section 313 of this law which established what has come to be known as the toxic release inventory (TRI).
- o In 1987, the United States signed the Montreal Protocol, an international agreement to ban the production and sale of chemicals believed to be destroying the ozone layer. At the time, many sterilizers were using a nonflammable compound known as "12/88", an EtO-CFC blend. At present, a non-explosive, EtO-HCFC blend is available, at a price premium to 100% EtO, and is being used by at least some in the major source category.

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- o In the late 1980s and early 90s, many sterilization companies installed and used wet acid scrubbers to control the high-concentration, low volume emissions from vacuum pumps. Some also applied controls to aeration rooms and backvents. During this time period several states began to require the use of such controls.
- o In March 1994, EPA proposed the EtO NESHAP, requiring maximum available control technology (MACT) for the vacuum pump and aeration vents. This proposal did not require any additional control for the chamber backvent exhaust.
- o In December 1994, the Agency published the final EtO NESHAP. For facilities using 10 or more tons EtO, this final regulation required a 99% emission reduction for vacuum pump and aeration vent emissions. In addition, the regulation required the chamber exhaust vent be routed to a control device already being used to control another stream to 99% (or 1 ppm, whichever is less) or directly to a control device capable of reducing those emissions by 99%. The regulation required that sterilizers install the necessary emission controls for compliance with EtO NESHAP requirements by December 1997.
- o The MACT requirement for exhaust backvents was based on comments to the effect that over 12% of the existing facilities, which were then using both nonflammable 12/88 and/or flammable 100% EtO, already controlled backvent emissions. Although the same controls could then be used for both gases, the safety issues presented now are quite different for sterilizers using 100% EtO. Further analysis of the data supporting the regulation shows that far fewer than 12% of sterilizers using 100% EtO could have been controlling backvent emissions, much less by routing them to controls for other vents.
- o The sterilizer industry studied the MACT requirements to control aeration and backvent emissions and then installed the equipment required for compliance with the EtO NESHAP. In June and July 1997, there were four EtO incidents which potentially involved emission control equipment.
- o On July 29, 1997, the US EPA stated that it would be prudent for all sterilizers to cease the installation and operation of the emission control systems.

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- o On December 9, 1997, the US EPA granted a one-year extension for compliance with the EtO NESHAP so that both industry and the Agency could further study the safety issues.

#### Emission Control Alternatives

To further understand the effects of the EtO NESHAP on the sterilization industry, one needs familiarity with the types of emission control systems being used in sterilization facilities.

At the time the EtO NESHAP was promulgated, only the following types of control equipment were available to the sterilization industry.

- o Acid Scrubber:

Acid Scrubbers have been used successfully to control primary vacuum pump emissions from sterilizers for over 10 years. For these high-EtO concentration, low-volume emission streams, an acid scrubber can economically achieve up to a 99.9% removal efficiency. An acid scrubber is much less effective (<99%) on low-EtO concentration, high volume streams like those from the aeration vents or chamber exhaust backvents.

- o Catalytic Oxidizer:

Catalytic oxidizer systems have been used in the sterilization industry to treat vacuum pump emissions, aeration vents and chamber exhaust backvents. In most facilities, catalytic oxidizers were typically installed to control only aeration and chamber exhaust vents, both of which are usually low-EtO concentration and high-volume emission sources. The problem is that if a high concentration, explosive EtO mixture is routed to a catalytic oxidizer, an explosion can result. It is highly unlikely to have an explosive mixture in the aeration vents. However, chamber exhaust vent emissions can be explosive if a high-EtO concentration is present in the sterilizer when the chamber exhaust is activated.

- o Thermal Oxidizer:

Some thermal oxidizers are also used by industry. These systems have applications and limitations similar to catalytic oxidizers.



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o Dry Bed Reactor:

Dry bed reactors eliminate EtO by a reaction that permanently binds it to the reactant. They operate at ambient temperatures and do not require preheating of the exhaust gas. They are most commonly specified and used for removing low levels of EtO from high volume exhaust streams but can be furnished for any flow capacity, typically, from 5 ppm to 300 ppm with spikes up to 10,000 ppm. Overfeeding can cause damage and possibly a fire.

Safety Incidents and Concerns

As mentioned in the regulation background, four EtO explosions occurred last summer when sterilization companies were in the process of installing emission control equipment to satisfy the EtO NESHAP requirements. All occurred in facilities that used a catalytic or thermal oxidizer to control their EtO emissions. Two occurred at EtO sterilization facilities and two at EtO fillers that repackaged EtO from drums into small cartridges used in smaller sterilizers. The two at EtO sterilization facilities happened shortly after the installation of catalytic oxidizers to treat the aeration and backvent emissions for compliance with the NESHAP. Further investigation is still underway on the definite cause of some of these incidents. Following is a brief summary of the EtO explosions previously reported to EPA:

1. Contract Sterilizer - VA:  
On 6/13/97, this EtO explosion occurred during the installation testing of a new catalytic oxidizer at the facility. There was no injury from the explosion, but the catalytic oxidizer and other equipment were damaged.
2. EtO Repackager - IN:  
On 6/24/97, an EtO fireball and explosion occurred in the gas filling room, completely destroying it. A catalytic oxidizer was used to control process emissions and this equipment was also damaged in the explosion. There were several injuries and one fatality from this incident.
3. Contract Sterilizer - MA:  
On 7/9/97, an EtO explosion occurred at the sterilization facility. A recently-installed catalytic oxidizer was in use to control emissions from the backvent. There was no injury from the explosion, but the catalytic oxidizer and other equipment were damaged. The fire marshall's investigation

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shows that the catalytic oxidizer was the ignition point for the explosion.

4. EtO Repackager - WI:

Also in 1997, an EtO fireball and explosion destroyed the filling building and the oxidizer emission control equipment. There was no injury associated with this explosion. This is regarded as a control equipment-related incident.

In addition, Griffith Micro Science had a similar EtO explosion that involved a catalytic oxidizer at its Los Angeles, CA facility. This incident occurred when an operator mistakenly opened the wrong sterilizer and the explosive mixture in the chamber was routed via the chamber exhaust vent to the open-flame oxidizer. The open flame ignited the mixture and an EtO explosion resulted. No injury resulted from this incident.

These incidents forced the EtO sterilization industry to further evaluate the safety of its equipment and operations. After hearing about the above incidents, several commercial sterilizers were concerned that similar incidents could occur in their facilities. In response, EOSA formed the Safety Subcommittee, composed of commercial sterilizers as well as emission control equipment manufacturers and testers. This Committee reviewed all past EtO incidents in the industry. They agreed to focus on the use of catalytic and thermal oxidizers as MACT emission control equipment. The Committee concluded that the oxidizer systems had not been properly integrated with traditional EtO sterilization process operations, that is, installation, operation and maintenance issues had not been sufficiently addressed by sterilizer operators. Since most oxidizers were being used by industry to control only the low-EtO concentration emissions from the aeration and chamber exhaust vents, the Committee agreed that improperly overfeeding the oxidizer system from the chamber backvent was the primary safety concern. Such overfeeding could always risk an explosion. Because the backvent is the primary safety concern, industry requests that the Agency reconsider the control requirements for this emission stream.

EOSA's Safety Subcommittee is in the process of identifying all known safety concerns associated with using oxidizers as emission controls for the sterilization process. It plans to publish a document that highlights these safety concerns and suggests potential preventive measures. The current draft of that document is enclosed.

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In addition, the Subcommittee is surveying industry on current or planned emission control systems and the safeguards that are or will be put in place. Responses have already been received from 25 sterilization facilities (covering 142 sterilization chambers). The preliminary survey results, which are enclosed, show the following:

- o Over 80% of facilities already have or plan to use a wet scrubber to control vacuum pump emissions. The remainder have or plan to use catalytic or thermal oxidation systems.
- o Only 20% of the responding plants currently have emission controls connected to chamber exhaust (backvent) while over 40% have emission controls already in operation to control aeration emissions.
- o 70% of the plants responding so far plan to or already use catalytic or thermal oxidizers to control chamber exhaust (backvent) and aeration emissions. The bulk of the remainder plan to use a wet scrubber.

Suggested Modifications to the EtO NESHAP

As outlined in the regulation background, the proposed EtO NESHAP did not have any additional requirement for control of chamber exhaust (backvent) emissions. Because of data presented to it during the comment period, however, EPA concluded that backvent emissions were already being sent to oxidizers such that the MACT requirements should be redefined to include such controls. After further review of this data by the EOSA Safety Subcommittee the sterilization industry disagrees with this conclusion as it applies to the use of 100% EtO.

Regardless, the final EtO NESHAP had the following emission control requirements for commercial EtO sterilizers that use 10 or more tons (which is the applicable category for virtually all commercial sterilization facilities):



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- o Primary Vacuum Pump Discharges: 99%
- o Aeration Room Vents: 99%
- o Chamber Exhaust Vents: connected to emission controls for other vents capable of 99% emission reduction or 1 ppm maximum outlet concentration, whichever is less stringent.

The EtO commercial sterilization industry presently uses approximately 3,920 tons of EtO annually. With this usage statistic the pollution control benefits to be achieved via the EtO NESHAP are as follows:

CURRENT EtO NESHAP REGULATION					
Emission Source	Total Emissions (%)	Total Emissions Subject to Control (tons/yr)	Required Efficiency (%)	Emission Reduction (tons/yr)	Total Permitted Emissions (tons/yr)
Vacuum Pumps	95.00	3,724	99.0	3,685.8	37.2
Aeration Vents	4.80	189	99.0	186.1	1.9
Chamber Exhaust (Backvents)	.20	8	99.0	7.9	0.1
TOTAL	100.00	3,920		3,881.8	39.2

As shown above, the EtO NESHAP provides for a total annual reduction of EtO emissions equal to 3,881 tons (or 99% of total EtO emissions); over 90% of this reduction is mandated to come from vacuum pump controls.

Because of EPA's warning to industry last summer, EOSA and industry have been spending a great deal of time investigating the safety concerns associated with the emission control equipment needed to meet this regulation and EOSA formed the Safety Subcommittee to discuss the safety issues.

As the NESHAP compliance date approaches, industry requests additional time to ensure safe compliance with the regulation. In

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addition, some modification to the final EtO NESHAP would greatly assist industry to safely meet the requirements without compromising the overall environmental benefits of the regulation. A memorandum of understanding/ compliance alternative incorporating industry's proposals is attached.

Additional Time Needed to Comply Safely with the EtO NESHAP

Industry believes that additional time is needed to safely comply with the EtO NESHAP. Most if not all sterilization facilities already have emission controls in place for the primary vacuum pump (which accounts for 95% of total EtO emissions). Vacuum pump controls should remain in place and be required to control emissions.

However, industry needs additional time to consider safe and economical control, installation, operation and maintenance alternatives applicable to aeration and chamber exhaust (backvent) emissions.

Since EPA notified industry "that it would be prudent to cease the installation and operation of their emission control equipment while the Agency continues its investigation of this matter," many sterilization companies still have not identified the technique(s) specific to their operations which would allow them to operate safely and comply fully with the regulation. These sterilizers have found that integration of catalytic or thermal oxidizers involves heretofore unrecognized safety considerations, concerns of the type that are currently being investigated by industry and the Agency.

The use of an acid scrubber for low concentration, high volume streams will not guarantee across-the-board 99% removal efficiency. Thus there are some sterilization facilities that still have to make a decision on the optimal emission control system for both the aeration and chamber exhaust vents. Most facilities are or appear to be considering installing the same emission control system for both low concentration sources and are using the acid scrubber system solely for the vacuum pumps.

In addition, some facilities which have installed new emission control equipment for the aeration and backvent emissions are still investigating implementation of all operation and maintenance safeguards needed to safely integrate it with their EtO operations as a whole. Since the same emission control system is or can be used for both the aeration and chamber exhaust emissions, industry

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requests additional time to meet the NESHAP control requirements for both sources. With the controls already in place for the vacuum pump emissions, over 90% of the environmental benefit from the EtO NESHAP would still be achieved.

#### Modified NESHAP Emission Control Requirements

The backvent system is activated and backvent emissions occur when a sterilization chamber door is opened to unload it. The backvent evacuates residual EtO from the chamber to provide a safe environment for the operator. Such controls are employed to meet OSHA regulations.

Since almost all sterilization cycles now used by industry contain some number of inert gas washes at the end of the cycle to purge residual EtO in the chamber and product, backvent emissions are generally very low EtO concentration, high-volume streams. In fact, the data presented above shows that backvent emissions are a very small source (0.2%) of the total EtO used in the sterilization process, not the 2% upon which the regulation was premised.

Therefore, the backvent emissions are a smaller source in today's environment compared to when the EtO NESHAP was proposed. According to operating data, the chamber exhaust (or backvent) emissions account for about 0.2% of total EtO emissions from the sterilization process. This percentage will vary slightly depending on the type of product, number of gas washes, and cycle pressure (vacuum).

It is important to point out, however, that while backvents are the smallest source of emissions from the sterilization process they are, conversely, the largest safety concern to the industry, in terms of both OSHA compliance and the possibility they present of overfeeding of control systems. Three of the most recent incidents in the sterilization industry might have involved high-EtO emissions from the backvent routed to an open-flame catalytic oxidizer emission control system. Accordingly, industry strongly urges the Agency to reconsider the NESHAP requirements for the backvent (or chamber exhaust) emissions.

Since the EtO NESHAP was designed as a performance regulation with a 99% overall reduction in EtO emissions, industry requests that EPA re-evaluate the specific control requirements for each emission source for the large EtO users ( $\geq 10$  tons/year). There are safer and more economical ways to achieve an overall 99% reduction in total EtO emissions that could be considered. Industry suggests

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the following emission control requirements for EtO emission sources:

- o Primary Vacuum Pump Discharges: 99.25%
- o Aeration Room Vents: 99.00%
- o Chamber Exhaust Vents: maximum outlet concentration of 7,500 ppm.

PROPOSED EtO NESHAP REGULATION						
Emission Source	Total Emissions (%)	Total Emissions Subject to Control (tons/yr)	Required Efficiency (%)	Emission Reduction (tons/yr)	Total Permitted Emissions (tons/yr)	Proposed Compliance Date
Vacuum Pumps	95.00	1,724	99.25	3,686.8	27.9	Dec. '98
Aeration Vents	4.80	188	99.00	185.1	1.9	12 months after reg.
Chamber Exhaust (Backvent)	.20	8.5	n/a	n/a	8.5	12 months after reg.
TOTAL	100.00	3,920		3,880.8	38.3	

\* Under the proposed scenario total industry emissions would be 1 ton/yr less than that permitted by the current NESHAP regulation.

Most, if not all, sterilizers already have systems in place that will meet the 99.25% requirement for vacuum pump emissions and will not need to install any additional equipment to achieve a maximum EtO concentration of 7,500 ppm (25% of EtO's Lower Explosive Limit). This 7,500 ppm limit is a maximum concentration which will prevent sterilizers from using the backvent as a primary emissions vent. Any measurement requirements for this concentration limit will need to be further defined. Using this proposed modified EtO NESHAP requirement, industry would achieve equal or greater reduction of EtO emissions than the EtO NESHAP, without compromising safety or imposing any additional economic burden on industry.

A specific proposal for additional time and modified control requirements is contained in the attached Memorandum of Understanding/Compliance Alternatives.

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#### Further information From Industry

Industry is still working on the following information to help EPA (and itself) review the EtO NESHAP requirements:

- o A document that highlights areas of safety concerns and suggests potential safeguards for the use of catalytic and thermal oxidizers to control EtO emissions (copy of draft enclosed).
- o A timeline for industry to safely review, design and install the necessary emission control equipment to comply with EtO NESHAP (draft enclosed).
- o An industry survey addressing emission control equipment and safeguards planned or in place at plants (results to date enclosed).
- o Suggested Testing Conditions and Parameters (including a sample test protocol).
- o Suggested Monitoring Requirements.

#### Summary

The EtO sterilization industry submits the following requests for EPA to consider before the current EtO NESHAP compliance date:

1. Because of the safety concerns associated with some equipment being used to control low-EtO concentration emissions from the aeration and chamber exhaust vents, industry requests additional time to review and install emission control technologies and/or safeguards necessary to operate safely and comply with EtO NESHAP requirements. Many facilities plan to use the same emission control system to control both the aeration and chamber exhaust emissions and, thus, will not be able to safely comply with the current December 1998 deadline (see survey results).
2. To maintain the environmental benefits of the EtO NESHAP without compromising safety or imposing additional burdens on industry, we request that EPA consider the following emission control requirements for the listed sources:



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- o Primary Vacuum Pump Discharges: 99.25%
- o Aeration Room Vents: 99.00%
- o Chamber Exhaust Vents: maximum outlet  
concentration of 7,500  
ppm.

On behalf of EOSA and my own company I would like to sincerely thank you and all the other Agency staff involved for all of your ongoing support to the sterilization industry. You have helped us organize industry efforts to fully review and begin to address the serious safety concerns associated with the control of process emissions. We trust that EPA will seriously consider industry's requests. Because many companies in industry are still reviewing the safety and environmental concerns associated with the NESHAP before they install or operate the necessary equipment, we ask that the Agency respond promptly to the concerns and suggestions set out above.

If you have any question at all, feel free to contact me at 972-519-9217 or EOSA at 202/296-6300. Industry representatives would be happy to meet with any EPA representative to further explain sterilization operations, safety and environmental concerns, and the formal requests outlined above.

Sincerely,



Kathleen A. Steiler, P.E.

Encls: draft Memorandum of Understanding/Compliance Alternative  
draft of time line document  
draft of Safety Committee document  
survey responses to 5/15/98



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June 9, 1998

Mr. David Markwordt  
Policy, Planning and Standards Division (MD13)  
Office of Air Quality Planning and Standards  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

**Subject: Typical Backvent Emissions and Concentration Estimates**

Dear Mr. Markwordt:

In our conversation last week, you requested some further information on current backvent emission and concentration estimates in the industry. In my June 2, 1998 letter to you, I stated that we estimate that the backvent emissions are about 0.2 percent of the total ethylene oxide (EtO) emissions from a typical commercial sterilization facility. I also requested that the US EPA consider implementing a maximum outlet concentration of 7500 ppm for chamber exhaust vents (backvents). The purpose of this letter is to provide some further support for the backvent emission estimate and typical backvent concentrations currently observed at commercial sterilization facilities.

The numbers presented in this letter are representative of the operations at Griffith Micro Science facilities. Because of FDA and customer requirements, commercial sterilization companies have generally similar sterilization cycles for similar products. Such cycles contain similar EtO usages, chamber vacuum pressures, and gas washes. Therefore, these backvent emission estimates should be rather typical of the entire industry. As a follow-up to this letter, I will review this letter with other sterilization companies that are members of the Ethylene Oxide Sterilization Association (EOSA) to determine that these numbers are typical of their operations.

#### **Current Backvent Emission Estimates**

As mentioned above, we currently estimate that the backvent emissions account for approximately 0.2 percent of the total EtO emissions. The breakdown of emissions from the typical sterilization process is not an exact or easy estimate. Such emission breakdowns are also very dependent on the types of products and sterilization cycles used at a facility. Table 1 (attached) contains the assumptions and backvent calculations from a common sterilization cycle at several Griffith Micro Science's facilities. This table supports the 0.2 percent estimate of total EtO emissions from a sterilization facility.

### **Typical Backvent Concentrations**

Typical backvent concentrations are also difficult to calculate and dependent on the sterilization cycle and product types. Griffith Micro Science has limited experience with measuring backvent emissions from a sterilization cycle. We have found that there is typically a large EtO concentration peak as soon as the backvent opens and the EtO concentration will quickly reduce to MUCH lower concentration levels. A typical chamber at Griffith Micro Science has a volume of about 1350 cubic feet and about 70% of this working volume is taken up by product. (For economic reasons, however, we try to utilize more than 70% of the chamber volume which makes these numbers somewhat conservative.) Therefore, about 30% free volume (about 405 cubic feet) is left in the chamber and contains any remaining EtO. Typical backvent blower rates are about 3000 cubic feet per minute. Assuming an ideal plug-flow, laminar flow evacuation of the chamber, the remaining EtO emissions will be evacuated in approximately 8 seconds. Such ideal conditions are certainly not present in typical backvent operations, but it does help understand why the EtO concentration peak quickly reduces to much lower levels. Based on some backvent emission measurements at Griffith plants, Figure 1 shows our best estimate of typical backvent concentration emissions. We believe that the maximum peak EtO concentration is about 7500 ppm. Within 3 minutes, this EtO concentration is typically reduced to 50 ppm or lower. The EtO peak level will vary with the cycle and product mixes, but Griffith has found that the 50 ppm or lower level after three (3) minutes is typical in most of our plants. Such measurements have been done to properly ensure protection of our operators when unloading chambers.

I appreciate your support and assistance in this regulatory matter. I hope this information helps you to better understand our current backvent estimates which were contained in my June 2, 1998 letter. As mentioned above, I will review this information with other EOSA sterilization companies to ensure that the information is consistent with the operations and experience at other sterilization companies.

If you have any further questions or need any more detailed support information, please feel free to call me at 972-519-9217.

Sincerely,

*Kathleen A. Steilen*

Kathleen A. Steilen, P.E.  
Environmental, Health & Safety Director

Attachments: Table 1 - Chamber Backvent Calculations  
Figure 1 - Typical EtO Backvent Concentrations

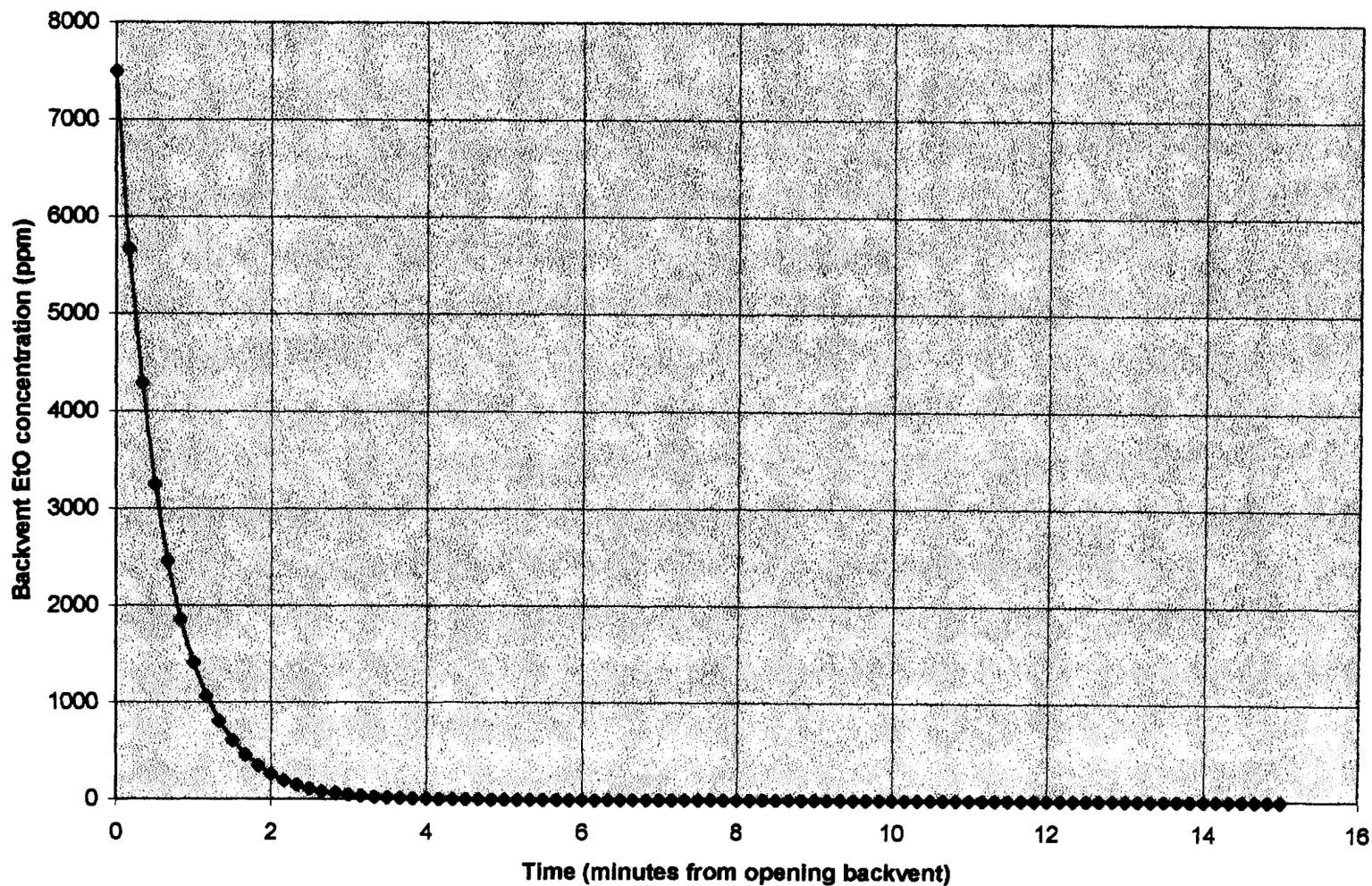
cc: Joe Hadley - EOSA Attorney

**Table 1**  
**CHAMBER BACKVENT CALCULATIONS**

<b>Purpose:</b>	Determine the approximate percentage of the total EtO usage that is vented in the chamber back vents.
<b>Assumptions:</b>	<ol style="list-style-type: none"> <li>1. The backvent emissions can be estimated using The Ideal Gas Law.</li> <li>2. The concentration in the chamber when the door is opened is about 20% LEL (or 6000 ppm). (confirmed with plant data)</li> <li>3. The chamber is full with product after one of our most popular cycles.</li> </ol>
<b>Calculations:</b>	
Volume of 1 mole = (at 1 atm & 130 F)	$V = n \cdot R \cdot T / P$ $V = (1 \text{ mole}) \cdot (0.08205 \text{ L atm/mol K}) \cdot (327.6 \text{ K}) / 1 \text{ atm}$ $V = 26.88 \text{ L}$ $m/V = 44.05 \text{ grams (MW of EtO)} / 26.88 \text{ L}$ $m/V = 1.64 \text{ g/L}$
With 20% LEL (or 6000 ppm) in backvent:	$m/V = (6000 / 1,000,000) \cdot (1.64 \text{ g/L})$ $m/V = 0.00984 \text{ g/L}$
Chamber volume for 13 pallet chamber is about 1350 ft <sup>3</sup> :	$V = 1350 \text{ ft}^3 \cdot (28.32 \text{ L / ft}^3)$ $V = 38232 \text{ L}$
About 70% of the actual chamber volume is occupied by product and not available for evacuation by backvent:	$\text{Available Volume} = 0.30 \cdot 38232 \text{ L} = 11470 \text{ L}$ $\text{mass/chamber} = (0.00984 \text{ g/L}) \cdot (11470 \text{ L}) / (453.6 \text{ g/lb})$ $\underline{0.25 \text{ lb/chamber}} \quad (\text{per each cycle})$
Therefore, there is a total of 0.25 lb EtO available to be evacuated by the the backvent. Our most common load has a total EtO gas charge of 140 lb EtO for a 13-pallet chamber	
Backvent % of EtO charge = (mass of EtO in backvent) / (Total EtO charge to chamber)	
Backvent % = (0.25 lb/chamber) / (140 lb/chamber)	
Backvent % = 0.00179 or <u>0.179 %</u>	



**Figure 1**  
**Estimated EtO Backvent Concentration vs. Time**  
(using 1350 cu ft chamber & 3000 cfm flow rate)





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# ***OAR Box 1936***

*Prepped by Charmelle Mathews*

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*Document Number:*

**76) II-B-7**

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*Docket Number:*

**A-88-03**



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**A-88-03**

*II - 13 - 7*

Date: April 28, 1986

Subject: Short-Term Emission Parameters for Ethylene Oxide Emissions From  
a Model Ethylene Oxide Sterilization Facility

From: David L. Newton *DLN*

To: David W. Markwordt  
ESED/CPB/CMS (MD-13)  
U. S. Environmental Protection Agency  
Research Triangle Park, N.C. 27711

I. Purpose

This memorandum presents short-term emission modeling parameters for a large model ethylene oxide (EO) sterilization facility. The parameters are intended for use in the screening analysis of health effects from short-term exposure to EO emitted from sterilization chambers.

II. Background

The Health Industry Manufacturers Association (HIMA) has conducted a survey of EO use and EO emission parameters among its members. The HIMA survey consists of questionnaires that have been completed by 95 facilities. These data have been provided to EPA to perform risk analyses. Additional data on EO sterilization have been collected from plant visits and test reports.

A model plant and emission parameters have been developed from the data base described above and are discussed in the following sections.

III. Model Plant

The model plant represents a large sterilization facility and contains six identical sterilization chambers, each having an internal volume of 28.32 m<sup>3</sup> (1,000 ft<sup>3</sup>). A diagram of the model plant is presented in Figure 1. Each chamber has its own dedicated vacuum pump, exhaust fan, and two emission stacks. Each sterilization chamber is filled with 22,680 g (50 lb) of pure EO for a sterilization cycle.

IV. Chamber Operation and Emission Parameters

Emission parameters are a function of sterilization chamber operating parameters. The chamber parameters will be discussed first, followed by a discussion of the emission parameters.

Chamber parameters. Chamber parameters can vary with the type of product sterilized and the sterilant gas mixture used.<sup>1-4</sup> Discussion here will be limited to sterilization with pure EO because it produces the greatest EO emissions compared to EO/CO<sub>2</sub> or EO/Freon mixtures.

The sterilization process consists of several basic steps. After the products to be sterilized are loaded into the chamber, the chamber is evacuated and humidified air and EO are injected until a specified pressure, relative humidity (RH), and EO concentration are reached. The sterilization cycle may last from 2 to 30 hours, depending on the product being sterilized.<sup>1-4</sup> After the prescribed sterilization period, the EO is removed from the chamber.<sup>1-5</sup> This is usually achieved by evacuation and repeated air washes.<sup>1-5</sup> After the evacuation/air wash cycles have been completed, products are sometimes aerated by pulling air through the chamber and out of an exhaust stack using a fan.<sup>1-5</sup>

The chamber parameters for the model plant are presented in Table 1. Chamber parameters reported include duration of evacuation/air wash/aeration periods, average flow rate, chamber pressure, and EO concentration. Representative values were selected from industry data or calculated assuming that EO behaves as an ideal gas and that none of the EO is adsorbed, absorbed, or reacted.<sup>1-4</sup>

The chamber operating cycles for the model plant are depicted in Figure 2, which is a plot of chamber pressure versus time. For purposes of modeling, it was assumed that the sterilization cycle lasts 8 hours and is carried out at an absolute chamber pressure of 0.53 atm (-14 in. Hg gauge pressure). The sterilization cycle is followed by 4 evacuation cycles of 10 minutes each that achieve an absolute chamber pressure of 0.098 atm (-27 in. Hg gauge pressure). Each evacuation cycle is followed by an air wash cycle that lasts 2 minutes. The final step is an in-chamber aeration cycle that lasts 30 minutes.

Emission parameters. Emission parameters are assumed to be identical for each chamber and are presented in Tables 2 through 6 for the five cycles in the process (i.e., four evacuation cycles and one aeration cycle) that emit EO. Emission parameters reported include duration of emission, average emission rate, stack diameter, stack height, average discharge velocity, and discharge temperature. Typical parameter values were selected directly from plant data or calculated from the chamber parameters in Table 1.

## V. Modeling Scenario

The short-term emission scenario selected for modeling represents a worst-case situation in which all six sterilization chambers are vented simultaneously to the atmosphere. The following assumptions are made for this scenario:

1. All of the EO initially injected into the chambers is exhausted through the stacks; implicit in this assumption are the further assumptions that none of the EO is adsorbed, absorbed, or reacted in the chambers and that none of the EO is discharged to the drain;

2. The exhaust temperature remains constant; and

3. During each evacuation cycle and the aeration cycle, the E0 emission rate decays exponentially over time and is described by the following equation:

$$x_t = x_0 e^{-Qt/V}$$

where

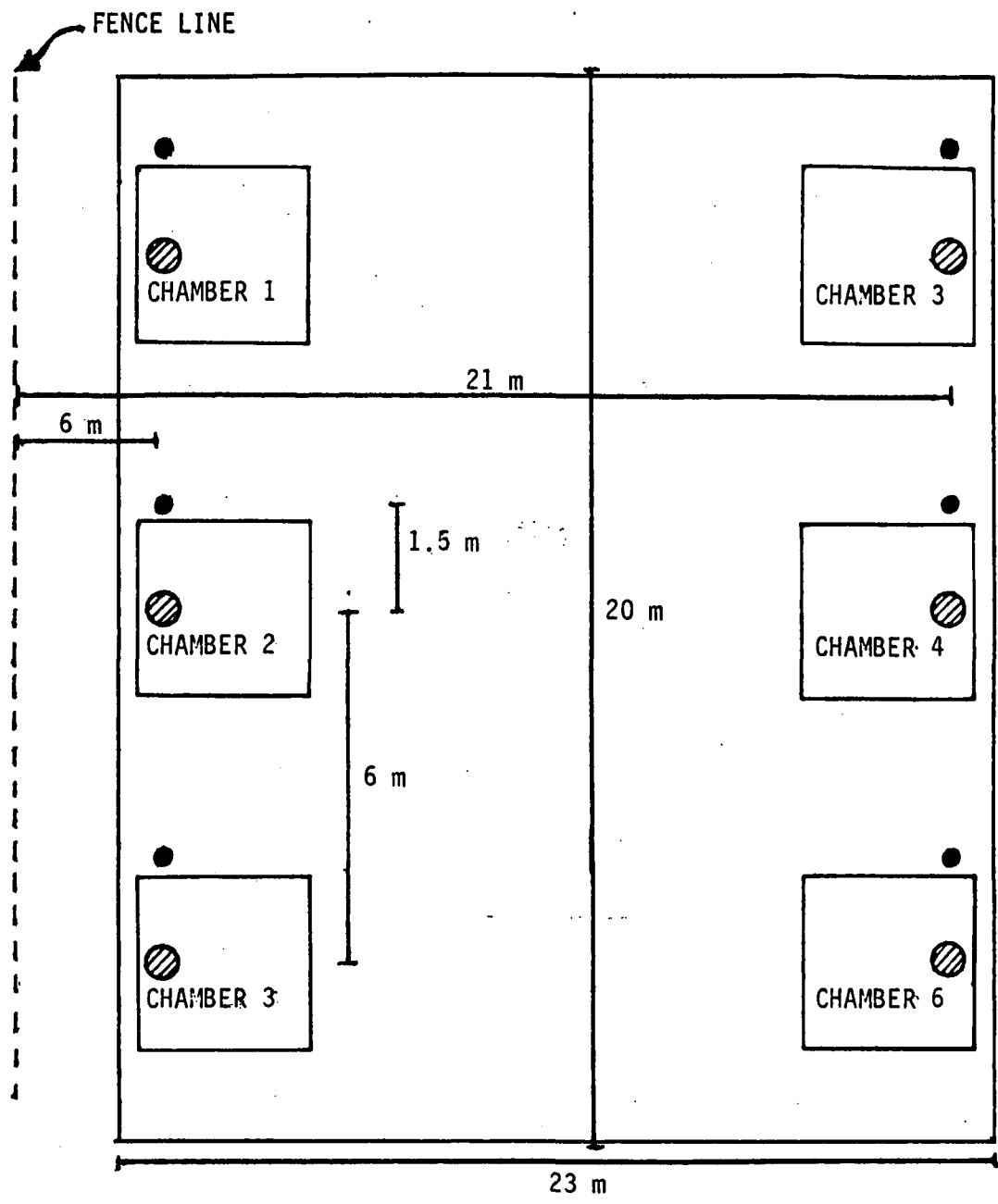
$x_t$  = E0 emission rate at time  $t$

$x_0$  = initial E0 emission rate

$Q$  = exhaust flow rate

$V$  = chamber volume

The total emission rate from the six sterilization chambers versus time is plotted in Figure 3.



BUILDING HEIGHT = 6.1 m

Figure 1. Model Plant Diagram -- Top View

Each chamber has volume of  $28.32 \text{ m}^3$  ( $1000 \text{ ft}^3$ )

● = Exhaust stack for aeration cycle

● = Exhaust stack for evacuation cycles



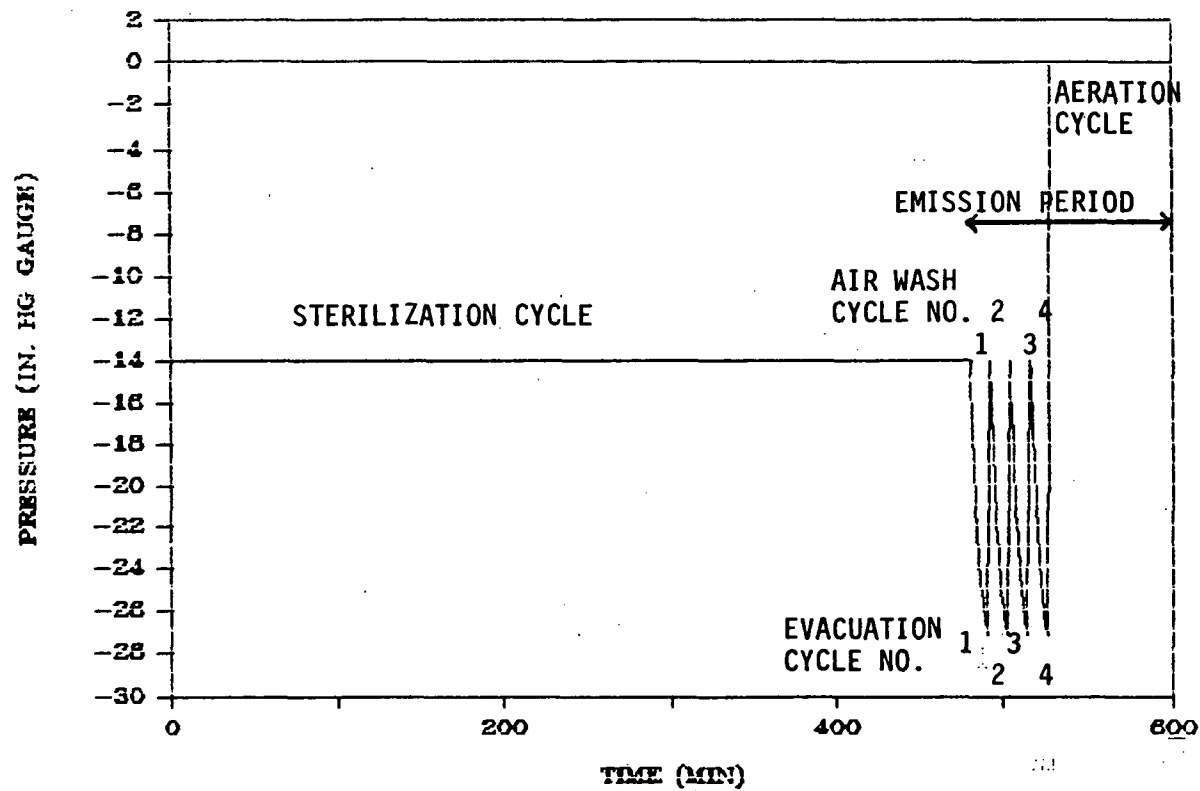


Figure 2. Chamber pressure relative to atmospheric pressure versus time.

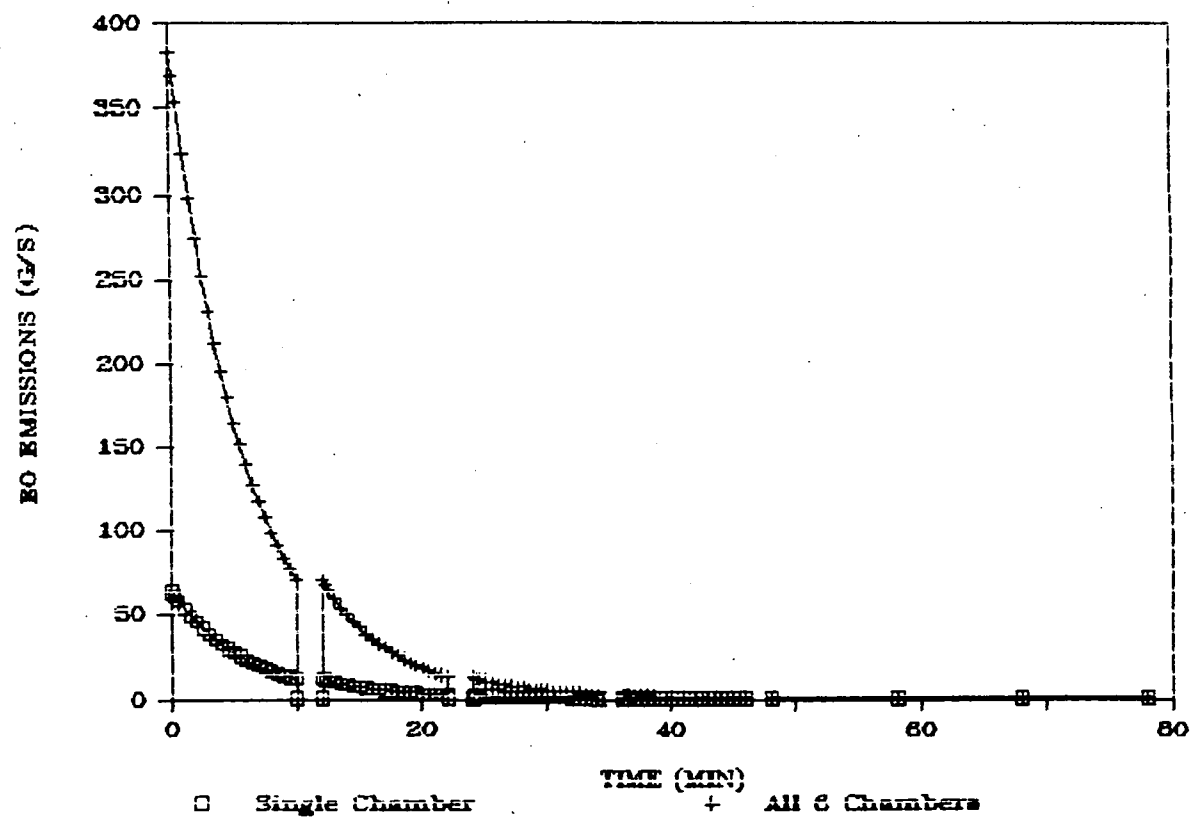


Figure 3. Plot of EO emissions versus time for a single chamber and for all 6 chambers at the model plant.

a, b

TABLE 1. STERILIZATION CHAMBER OPERATING PARAMETERS

Chamber Cycle	Duration (min)	Average Flow Rate (actual m3 c per min)	Initial Vacuum (in. Hg)	Final Vacuum (in. Hg)	Initial EO Con- centration (mg/m3)	Initial EO Con- centration (ppm)	Final EO Con- centration (mg/m3)	Final EO Con- centration (ppm)
Evacuation No. 1	10	1.23	-14	-27	800,847	887,015	146,889	887,015
Air Wash No. 1	2	—	-27	-14	146,889	887,015	146,889	162,694
Evacuation No. 2	10	1.23	-14	-27	146,889	162,694	26,942	162,694
Air Wash No. 2	2	—	-27	-14	26,942	162,694	26,942	29,841
Evacuation No. 3	10	1.23	-14	-27	26,942	29,841	4,942	29,841
Air Wash No. 3	2	—	-27	-14	4,942	29,841	4,942	5,473
Evacuation No. 4	10	1.23	-14	-27	4,942	5,473	906	5,473
Air Wash No. 4	2	—	-27	0	906	5,473	906	534
Aeration Cycle	30	5.93	—	—	906	534	2	1

a

Assumes chamber temperature is maintained at 316 K during evacuation and air wash cycles.

A temperature of 294 K is assumed for the aeration cycle.

b

Based on an EO injection of 22,680 g (50 lb).

c

Average flow at pump/stack exit.

TABLE 2. EMISSION PARAMETERS FOR EVACUATION NO. 1

Parameter	Input Value	Basis for Input Value	Reference
Average emission rate	31 g/s	Plant data	1-4
Duration	10 min	Plant data	1-4
Vent height	8 m	Plant data	1-4
Vent diameter	5.09E-02 m	Plant data	1-4
Average discharge velocity	10 m/s	Plant data	1-4
Discharge temperature	316 K	Plant data and assumption	1-4
Distance to boundary			
Chambers 1-3	6 m	Assumed	
Chambers 4-6	20.6 m	Assumed	

TABLE 3. EMISSION PARAMETERS FOR EVACUATION NO. 2

Parameter	Input Value	Basis for Input Value	Reference
Average emission rate	6 g/s	Plant data	1-4
Duration	10 min	Plant data	1-4
Vent height	8 m	Plant data	1-4
Vent diameter	5.09E-02 m	Plant data	1-4
Average discharge velocity	10 m/s	Plant data	1-4
Discharge temperature	316 K	Plant data and assumption	1-4
Distance to boundary			
Chambers 1-3	6 m	Assumed	
Chambers 4-6	20.6 m	Assumed	

TABLE 4. EMISSION PARAMETERS FOR EVACUATION NO. 3

Parameter	Input Value	Basis for Input Value	Reference
Average emission rate	1.04 g/s	Plant data	1-4
Duration	10 min	Plant data	1-4
Vent height	8 m	Plant data	1-4
Vent diameter	5.09E-02 m	Plant data	1-4
Average discharge velocity	10 m/s	Plant data	1-4
Discharge temperature	316 K	Plant data and assumption	1-4
Distance to boundary			
Chambers 1-3	6 m	Assumed	
Chambers 4-6	20.6 m	Assumed	

TABLE 5. EMISSION PARAMETERS FOR EVACUATION NO. 4

Parameter	Input Value	Basis for Input Value	Reference
Average emission rate	1.90E-01 g/s	Plant data	1-4
Duration	10 min	Plant data	1-4
Vent height	8 m	Plant data	1-4
Vent diameter	5.09E-02 m	Plant data	1-4
Average discharge velocity	10 m/s	Plant data	1-4
Discharge temperature	316 K	Plant data and assumption	1-4
Distance to boundary			
Chambers 1-3	6 m	Assumed	
Chambers 4-6	20.6 m	Assumed	



TABLE 6. EMISSION PARAMETERS FOR AERATION CYCLE

Parameter	Input Value	Basis for Input Value	Reference
Average emission rate	1.43E-02 g/s	Plant data	1-4
Duration	30 min	Plant data	1-4
Vent height	8 m	Plant data	1-4
Vent diameter	0.14 m	Plant data and eng. judgement	1-4,6
Average discharge velocity	6.45 m/s	Plant data and eng. judgement	1-4,6
Discharge temperature	294 K	Assumption	
Distance to boundary			
Chambers 1-3	6 m	Assumed	
Chambers 4-6	20.6 m	Assumed	

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Date: February 7, 1991

Subject: Costing of Control Alternatives for Rear Chamber  
Exhaust Emissions  
Commercial Sterilization NESHAP  
EPA Contract 68-02-3817; ESD Project 84/03  
MRI Project 7723-K

From: Val deOlloqui  
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#### I. Background

This memorandum presents the cost of controlling ethylene oxide (EO) emissions from rear chamber exhaust processes. The rear chamber exhaust is an exhaust system at the back of the sterilizer that evacuates EO-laden air from the chamber while the chamber is being unloaded (and reloaded). The rear chamber exhaust typically consists of a butterfly valve in the ductwork that opens when the sterilizer door is automatically cracked after the sterilization cycle is completed. As the chamber door is being cracked, a roof-mounted blower automatically switches on and pulls fresh air through the chamber. The use of the rear chamber exhaust assists facilities in meeting the EO permissible exposure level set by the Occupational Safety and Health Administration.<sup>1</sup>

In November 1989, the Health Industry Manufacturers' Association (HIMA) conducted a survey of 14 companies (23 facilities) to determine the prevalence of rear chamber exhaust use. Although these facilities represent only 12 percent of the facilities in the EPA commercial sterilization (CS) data base, they represent 40 percent of the annual EO use. Of the 156 chambers these companies operate, 35 chambers (22 percent) do not have rear chamber exhausts.<sup>2</sup> Typically, these chambers are less than 7 cubic meters ( $m^3$ ) (<250 cubic feet [ $ft^3$ ]) in volume. Based on this HIMA survey, facilities with total sterilizer volumes less than 7  $m^3$  (250  $ft^3$ ) were determined not to have rear chamber exhaust from information obtained on sterilizers of this size and, therefore, are not included in this cost analysis.

Of the 188 facilities in the 1989 EPA CS data base, the 250 ft<sup>3</sup> cutoff for rear chamber exhaust excludes 61 facilities, or 32 percent. Therefore, 127 facilities are assumed to have rear chamber exhausts. Unless otherwise noted, all subsequent analyses in this memorandum are based on data for these 127 facilities.

## II. Rear Chamber Exhaust Emission Estimates

Two approaches were taken to estimate rear chamber exhaust emissions. First, a sensitivity analysis was performed to determine the percentage of EO charged to the sterilizer that is emitted via the rear chamber exhaust. This analysis involved the following sterilization cycle parameters: (1) percentage of sterilizer filled with product, (2) the number of evacuations (air washes) performed, (3) the sterilizer operating (i.e., dwell) pressure, and (4) the vacuum and vent pressures during the evacuations (see Table 1). Because sterilizer operating parameters were not available from CS facilities, operating parameters for this analysis were obtained from a sterilizer manufacturer.<sup>3</sup>

The ideal gas law was used to determine the percent of initial EO charged to the sterilizer that remains in the chamber void volume after the sterilization cycle is completed. All EO in the void volume is assumed to be subsequently emitted via the rear chamber exhaust. Based on an initial sterilizer chamber concentration of 600 milligrams per liter (mg/P) (0.037 lb/ft<sup>3</sup>), these percentages were converted to parts per million volume (ppmv) to determine the final EO concentration in the chamber prior to the rear chamber exhaust cycle (see Table 1).<sup>4</sup> Because the rear chamber exhaust has a large flow rate (84 m<sup>3</sup>/min [3,000 ft<sup>3</sup>/min]), diluent air entering the chamber will lower the EO concentration as the rear chamber exhaust cycle proceeds.<sup>1</sup> (Some EO may evolve from the product during the rear chamber exhaust cycle, but this amount is negligible compared to the EO concentration in the void volume).<sup>5</sup> Therefore, EO concentrations from the rear chamber exhaust vent may be equivalent to void volume concentrations when the rear chamber exhaust cycle is initiated, but as the cycle progresses EO concentrations will decrease rapidly.

The results of the sensitivity analysis (see Appendix A) indicate that the percent of EO use emitted from the rear chamber exhaust varies considerably with sterilizer operating parameters. Therefore, an alternative method was used to develop an emission estimate based on data from a July 1989 EPA Section 114 letter. Six of the facilities that responded to that letter provided information about the distribution of EO emissions to postevacuation processes. For these six facilities, 60 percent of post-evacuation emissions are emitted from the aeration room and 40 percent from the rear chamber exhaust.<sup>6</sup> In previous memoranda and documentation, it was estimated that 5 percent of

the EO charged to the sterilizer was released during the aeration process. However, for this and future cost analyses, it will be assumed that 5 percent of the total EO charged to the sterilizer is released from postevacuation processes (i.e., rear chamber exhaust and aeration room processes). Therefore, based on the emission distributions for the aforementioned six CS facilities, for this and subsequent cost analyses, uncontrolled emissions from the rear chamber exhaust and aeration room will be equal to 2 and 3 percent respectively, of the total EO use. Additionally, as shown in Appendix A, a 2 percent estimate is the median value for facilities that use 12/88 (EO/CFC) sterilant gas, which comprise the majority of CS facilities.

### III. Control Options for Rear Chamber Exhaust Emissions

Several control methods were considered for rear chamber exhaust emissions.<sup>5</sup> Two methods were selected for this cost analysis: (1) dedicated add-on controls and (2) manifolding the rear chamber exhaust emissions to the aeration room control. (Manifolding the rear chamber exhaust vents and the sterilizer vents to an acid/water scrubber was also considered. However industry contacts indicated that due to the high flow rates from rear chamber exhaust vents this alternative would not be technically feasible). These control methods were selected because other methods considered (e.g., decreasing the evacuation pressure or increasing the number of evacuations could adversely affect some products and packaging or affect product schedules. Because sterilization cycles are product dependent, any control method that would require cycle modifications would be difficult to apply to the CS industry, which sterilizes a variety of products. Also, cost impacts are difficult to determine for cycle modifications.

Costs were developed for the following control systems: (1) an acid/water scrubber, (2) catalytic oxidation, and (3) a gas/solid reaction system. The costs for acid-water scrubbing are for a dedicated unit to control only rear chamber exhaust emissions. The costs for catalytic oxidizers and gas/solid reactors are for dedicated controls and for rear chamber exhaust emissions manifolded to the aeration room control.

For this cost analysis, if a facility has more than two sterilizers, the control device is sized for a flow rate of  $168 \text{ m}^3/\text{min}$  ( $6,000 \text{ ft}^3/\text{min}$ ). This methodology simulates the control cost if two sterilizers were to utilize the rear chamber exhaust simultaneously. If a facility has one or two sterilizers, the control is sized for a flow rate of  $84 \text{ m}^3/\text{min}$  ( $3,000 \text{ ft}^3/\text{min}$ ). This methodology is based on the assumption that a facility with two sterilizers or less will rarely need to evacuate both sterilizers simultaneously and is, therefore, consistent with the methodology developed in the sterilizer vent cost analysis.

For the dedicated control scenarios, the control units are sized based on the rear chamber exhaust flow rate. For facilities with one or two chambers, costs are developed for an 84 m<sup>3</sup>/min (3,000 ft<sup>3</sup>/min) control; for facilities with more than two chambers a 168 m<sup>3</sup>/min (6,000 ft<sup>3</sup>/min) control unit is costed.

For the manifold control scenario, the control devices are sized based on the combined flow rate from the aeration units and the flowrate that normally would go to a dedicated rear chamber exhaust control. If a facility has one or two chambers, a 168 m<sup>3</sup>/min (6,000 ft<sup>3</sup>/min) control device is substituted for one of the aeration control devices. For facilities with more than two chambers, a 252 m<sup>3</sup>/min (9,000 ft<sup>3</sup>/min) is substituted. (This cost analysis also includes the cost of controlling the remaining aeration emissions and the cost of the aeration units. The methodology for the aeration control cost analysis is discussed in a separate memorandum.)<sup>8</sup>

#### A. Acid/Water Scrubbers

Acid-water scrubbers can achieve EO removal efficiencies of 99 percent or greater for sterilizer vent emissions.<sup>9</sup> The high concentrations of EO from sterilizer vents are responsible for these high efficiencies.<sup>9</sup> However, the EO removal efficiency of acid/water scrubbers used to control rear chamber exhaust emissions would be less due to the low EO concentrations associated with this emission source. Because there are no control efficiency test data available for acid-water scrubbing of rear chamber exhaust emissions, a control efficiency of 98 percent was chosen as a best-case estimate.

Vendors were contacted to discuss controlling rear chamber exhaust emissions with an acid/water scrubber. These vendors indicated that due to the high flow rates of the rear chamber exhaust, it would not be technically feasible to manifold rear chamber exhaust emissions to the sterilizer control and that a dedicated acid/water scrubber should be used.<sup>10,11</sup> Presently, one vendor is developing an acid-water scrubber for an aeration room with a flow rate of 336 m<sup>3</sup>/min (12,000 ft<sup>3</sup>/min).<sup>10</sup> Based on the projected costs for that scrubber, the vendor developed a capital cost estimate (freight-on-board [FOB]) for a 168 m<sup>3</sup>/min (6,000 ft<sup>3</sup>/min) unit.<sup>10</sup>

Because acid-water scrubbers for rear chamber exhaust vents have not been developed, the vendor could not provide estimated installation costs. Therefore, based on costing procedures described in EPA's Office of Air Quality Planning and Standards (OAQPS) Control Cost manual, a total installed cost was developed by multiplying the capital cost (FOB) of the scrubber by an installation factor of 2.2.<sup>12</sup> These costs were increased to ensure that vendor costs were not understated and that every aspect of the installation of the scrubber was taken into consideration. (This methodology differs from that used to

develop costs for acid-water scrubbing of sterilizer vent emissions. Scrubbers for sterilizers, which are designed differently from one that would control rear chamber exhaust emissions, have been in use at CS facilities for several years. Therefore, the vendor was able to provide approximate installation costs for those units).

Capital costs included ductwork to manifold all rear chamber exhaust vents at a facility to a common control unit, the cost of the scrubber, and the installation costs outlined in the EPA Cost Manual.<sup>12</sup> Operating costs were developed based on the cost methodology outlined in the sterilizer vent cost memo and were based on costs for existing scrubbers that have acid-water volumes comparable to the 84 and 168 m<sup>3</sup>/min (3,000 and 6,000 ft<sup>3</sup>/min) scrubbers.<sup>7,10</sup> These operating costs include the cost of acid and neutralizing base (see Appendix B). Disposal costs were determined using a transportation distance of 1,000 miles, because most CS facilities (except those in Puerto Rico) are located within 1,000 miles of one of the recovery facilities.<sup>13-15</sup> Disposal costs were determined on a no charge, no credit basis (see Appendix B). A detailed description of the scrubber cost analysis is presented in Appendix C.

#### B. Catalytic Oxidation System

Cost estimates (FOB) for 84, 168, and 252 m<sup>3</sup>/min (3,000, 6,000 and 9,000 ft<sup>3</sup>/min) catalytic oxidation systems were obtained from a vendor (see Appendix D).<sup>16</sup> Capital costs included ductwork, the cost of the catalytic oxidizer, and associated installation costs. Disposal costs for the spent catalyst include transportation to and landfilling at a local industrial landfill. For the dedicated scenario, ductwork was costed to manifold all rear chamber exhaust vents at a facility to one control device. For the manifolding scenario, ductwork was costed to manifold all rear chamber exhaust vents and all aeration units to a common control device (see Appendix E).

#### C. Gas/Solid Reactor System

The gas/solid reactor system consists of a proprietary solid reactant that chemically converts EO and binds it to the solid. This reactant is contained in multiple boxes or cells that are arranged in a certain order dependent on the flow rate through the reactor. The system operates at room temperature. The product is a chemically stable compound that can not convert back to EO and can, therefore, be landfilled or returned to the vendor for recycling.

Cost estimates for 84, 168, and 252 m<sup>3</sup>/min (3,000, 6,000 and 9,000 ft<sup>3</sup>/min) gas/solid reaction systems were obtained from a vendor.<sup>17</sup> Capital costs include ductwork, the cost of the gas/solid reactor, and associated installation costs. For the dedicated scenario, ductwork was costed to manifold all rear



chamber exhaust vents at a facility to one control device. For the manifolding scenario, ductwork was costed to manifold all rear chamber exhaust vents and all aeration units to a common control device (see Appendix E). Disposal costs for spent reactant are based on the reactant being returned to the control device vendor for recycling on a no charge, no credit basis.<sup>18</sup> A distance of 1,500 miles was used to calculate transportation costs for disposal, because most CS facilities are within 1,500 miles of the recycling facility.

#### D. Results

A summary of the total annual costs, emission reductions, and cost-effectiveness estimates for the five control scenarios are provided in Table 1. Detailed cost estimates for one facility are presented in Tables 2, 3a, 3b, 4a, and 4b (for acid/water scrubber, catalytic oxidizer and gas/solid reactor, respectively). Costs were converted to fourth quarter 1987 dollars using Chemical Engineering cost indices (see Appendix F).<sup>19-24</sup> Costs were rounded before being used in the next calculation. Capital and annual costs were rounded to three significant figures; cost-effectiveness values were rounded to two significant figures. The programs and the data bases used to perform the cost analyses are included in Appendix G and confidential Appendix H, respectively.

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**APPENDIX A.**  
**REAR CHAMBER EXHAUST EMISSIONS SENSITIVITY ANALYSIS**

## SENSITIVITY ANALYSIS OF REAR-CHAMBER EXHAUST EMISSIONS

The following sensitivity analysis was conducted to determine the effect of several variables on the amount of EO emitted from the rear-chamber exhaust. The three variables in this analysis are the percent of vessel volume filled with product [X], the number of evacuations [N], and the vacuum pressure drawn,  $P_v$ . The following equation was used to develop this analysis:

Percent of EO charge emitted to rear exhaust =

$$[P_v/P_d][P_v/P_{atm}]^{N-1}(1-X)(100)$$

where:

$P_d$  = dwell pressure

$P_v$  = vacuum pressure drawn

$P_{atm}$  = atmospheric pressure or pressure to which vessel is allowed to vent

N = No. of evacuations drawn

X = fraction of vessel volume filled with product

Assume good mixing and ideal gas behavior

The concentrations in ppmv are calculated assuming an initial sterilizer concentration of 600 mg/l (necessary lethal dose). Multiplying the percent EO to the rear exhaust by this initial concentration and correcting for temperature and pressure yields the concentration to the rear exhaust.

TABLE A-1. REAR CHAMBER EXHAUST SENSITIVITY ANALYSIS<sup>3,32</sup>

		[N] <sup>a</sup>		
		2	3	4
<u>12/88 gas<sup>c</sup></u>				
[X] <sup>b</sup>	0.60	6.68 (22,979)	3.34 (11,489)	1.67 (5,745)
	0.70	5.01 (17,234)	2.51 (8,617)	1.25 (4,309)
	0.85	2.51 (8,617)	1.25 (4,309)	0.63 (2,154)
<u>12/88 gas<sup>d</sup></u>				
[X]	0.60	0.52 (1,794)	0.10 (343)	0.02 (66)
	0.70	0.39 (1,346)	0.07 (257)	0.01 (49)
	0.85	0.20 (673)	0.04 (129)	0.01 (25)
<u>Pure EO<sup>e</sup></u>				
[X]	0.60	1.46 (5,035)	0.28 (963)	0.05 (184)
	0.70	1.10 (3,777)	0.21 (723)	0.04 (138)
	0.85	0.55 (1,888)	0.11 (361)	0.02 (69)

<sup>a</sup>[N] is the number of evacuations.

<sup>b</sup>[X] is the fraction of the sterilizer volume filled with product.

<sup>c</sup> $P_v = 7.35$ ,  $P_d = 22$ ,  $P_a = 14.7$  (psia)

<sup>d</sup> $P_v = 1.5$ ,  $P_d = 22$ ,  $P_a = 7.84$  (psia)

<sup>e</sup> $P_v = 1.5$ ,  $P_d = 7.84$ ,  $P_a = 7.84$  (psia)

<sup>f</sup>Values outside parentheses indicate the percent of EO used that is emitted from the rear chamber exhaust; values within parentheses indicate the EO concentration in ppmv at the end of [N] evacuations. Assumed 600 mg/l as the sterilizing concentration.

The operating parameters used for both gas mixtures were obtained from a sterilizer vendor. Sterilizer cycles that had extremely low vacuum pressures (e.g., 1.5 psia) were assumed to be vented to a pressure lower than atmospheric.

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**APPENDIX B.**

**CHEMICAL AND WASTE DISPOSAL COSTS FOR SCRUBBER**

The following prices were used to cost the operating materials.

<u>50 percent H<sub>2</sub>SO<sub>4</sub><sup>33</sup> electrolyte-grade</u>	<u>50 percent NaOH<sup>34</sup> industrial-grade</u>	<u>Chlorine filters</u>
\$0.0702/lb	<2 drums \$0.110/lb	Filter housing <sup>35</sup> - \$41.50 each
	3-9 drums \$0.0802/lb	Filter--\$15 each <sup>36</sup>
	>9 drums \$0.0752/lb	Installation--\$20 each <sup>36</sup>

Disposal was costed for shipping a 63 percent aqueous ethylene glycol solution (ρ~10 lb/gal) a distance of 1,000 miles. Estimates from two freight companies were averaged for shipping 55-gal drums.<sup>37,38</sup> One company was contacted to cost the shipment of this solution in bulk quantities by tank truck.<sup>39</sup> The prices quoted, in 1986 dollars, were converted to 1987 dollars based upon Chemical Engineering Cost Indices.<sup>19,21</sup> The disposal costs were calculated for each facility based upon the following:

<u>Weight of solution for disposal, per year</u>	<u>Cost, 1987 dollars</u>
<42,000 lb (drums)	\$0.110/lb <sup>37,38</sup>
=>42,000 lb (bulk)	\$0.068/lb <sup>39</sup>

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**APPENDIX C.**  
**SCRUBBER COST ANALYSIS**

### ASSUMPTIONS FOR SCRUBBER ANALYSIS

1. The example (fictitious) facility has four sterilizers and uses 65,700 lb of EO annually. The facility parameters were calculated using the following assumptions:

a. EO-tot (lb) is the total amount of EO (lb) used annually by the facility, i.e., the sum of EO use.

b. UNC\_RCE is the amount of EO (lb) emitted annually from the rear chamber exhaust vents, assumed to be 2 percent of EO use.

c. NESHAP is the amount of EO (Mg/yr) that would be released after control of the rear chamber exhaust vent.

f. REDUCE is the incremental amount of EO (Mg/yr) that would be reduced if rear chamber exhaust controls are implemented.

2. For all calculations, a removal efficiency of 98.0 percent was assumed for the scrubber.

3. Each tank of the scrubber initially holds 198 gal H<sub>2</sub>O and 19.8 gal H<sub>2</sub>SO<sub>4</sub>. The manufacturer recommends that the tank be regenerated (i.e., drained, rinsed, and refilled) after 2,000 lb EO have been treated.<sup>40</sup>

a. 19.8 gal H<sub>2</sub>SO<sub>4</sub> = 1.42 kg-mole H<sub>2</sub>SO<sub>4</sub> ( $\rho$  = 1.834; MW = 98.08)  
 $2\text{NaOH} + \text{H}_2\text{SO}_4 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$ ; 1.42 kg-mole H<sub>2</sub>SO<sub>4</sub> requires 2.84 kg mole NaOH to neutralize. Neutralization will produce 2.84 kg-moles H<sub>2</sub>O and 1.42 kg mole Na<sub>2</sub>SO<sub>4</sub>. Use 50 percent (w/w) NaOH to neutralize; each 55-gal drum of 50 percent NaOH weighs 700 lb, i.e., 350 lb NaOH; need 2.84 kg-moles or 250 lb NaOH to neutralize.<sup>34,41</sup>

b.  $\text{C}_2\text{H}_4\text{O (EO)} + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_4(\text{OH})_2$  (ethylene glycol); 2,000 lb EO = 20.571 kg-moles EO (MW = 44.1).<sup>42</sup>

c. At 98 percent conversion yield is 20.10 kg-moles or 298 gal ethylene glycol (EG) (MW = 62.07;  $\rho$  = 1.1088).<sup>42</sup>

d. At 98 percent conversion, 20.363 kg-moles H<sub>2</sub>O have reacted. 41.64 kg moles H<sub>2</sub>O originally available (MW = 18;  $\rho$  = 1); 21.27 kg-moles or 101 gal H<sub>2</sub>O remain unreacted.<sup>42</sup>

e. Weight of neutralized solution per tank: 1.42-kg mole Na<sub>2</sub>SO<sub>4</sub> = 202 kg Na<sub>2</sub>SO<sub>4</sub> (MW = 142.04); 2.84 kg-moles H<sub>2</sub>O (from neutralization) = 51 kg H<sub>2</sub>O; 250 lb (113 kg) H<sub>2</sub>O = from 50 percent NaOH solution; 100 gal

unreacted  $H_2O$  = 378 kg  $H_2O$ ; 301 gal EG = 1,264 kg EG; total wt = 2,008 kg = 4,427 lb.

f. Solution is 63 percent (w/w) EG. Add about 50 gal rinse water for each tank = 189 kg; total wt (+rinse  $H_2O$ ) = 4,845 lb; total gal (+rinse  $H_2O$ ) = 495 gal = 9 55-gal drums; wt per 55-gal drum = 538 lb.

4. Scrubber size based on flow rate from one chamber (i.e., 3,000  $ft^3/min$ ). This model is similar in size to the Model 50 scrubber.<sup>10</sup> Therefore, operating costs were based on these for a Model 50 scrubber. Cost of 3,000  $ft^3/min$  unit was extrapolated as  $\$45,000 \times (0.5)^{0.7}$

Piping costs for manifolding are explained in detail in Appendix E.

5. Find number of regenerations of scrubber required per year:

a. Number of tanks = scrubber model/100 = 1

b. Conversion capacity of scrubber = (no. of tanks)  $\times$  2,000 lb = 2,000 lb

c. Number of regenerations = UNC\_RCE (lb)/2,000, i.e., the amount of EO (lb) to be treated per year divided by the conversion capacity of the scrubber.

$1,314/2,000 = 0.66$  regenerations/yr

6. Cost of chlorine filter housing =  $(41.50) \times (\text{no. of tanks}) = \$42$

7. Calculate direct operating costs:

a. Labor =  $3,188 + (11.65) \times (16) \times (\text{no. of regenerations})$ . The \$3,188 is for general inspection of the system 15 minutes/shift, 3 shifts/day, 365 days/yr at \$11.65/person-hour. For the purposes of these cost analyses, it was assumed that each regeneration of the scrubber would require 2 people at 8 person-hours each, independent of scrubber size. System inspection was also assumed to be independent of scrubber size.

b. Sulfuric acid (50 percent  $H_2SO_4$ -electrolyte grade).

Assumed: 1 55-gal drum 50 percent  $H_2SO_4$ , i.e., 19.4 gal  $H_2SO_4$ , per scrubber tank.

No. of drums required = UNC\_RCE/2,000

Cost of acid = (no. of drums)  $\times$  (594 lb/drum)  $\times$  (\$0.0702/lb)  $\times$  (1.15)

15 percent added to cost to account for spillage

c. Caustic (50 percent NaOH-industrial grade). Unit cost of NaOH was calculated by first dividing total amount of EO (lb) per year to be

controlled at the facility by the conversion capacity of one tank, i.e., 2,000 lb EO, to find the total no. tanks/yr.

$$\text{UNC\_RCE}/2,000 = 1,314/2,000 = 0.66 = \text{No. tanks/yr}$$

$$250 \text{ lb NaOH required per tank} = 0.8 \times 250 = 164 \text{ lb/yr}$$

$$\text{Total drums/yr required by facility} = \text{total NaOH (lb)}/350 \text{ lb per drum; total drums} = 0.47$$

$$\text{If total drums} > 9, \text{ cost/lb} = 0.0752$$

$$\text{If total drums} = 3 \text{ to } 9, \text{ cost/lb} = 0.0802$$

$$\text{If total drums} = < 2, \text{ cost/lb} = 0.110$$

$$\text{Cost of caustic} = (\text{no. of drums}) \times (\text{cost/lb}) \times (700 \text{ lb/drum}) \times 1.15$$

15 percent added to account for spillage

d. Cost of chlorine filters. Each filter can dechlorinate ~200 gal H<sub>2</sub>O (or 1 tank); replace at each regeneration.

$$\text{Cost} = (\text{no. of regenerations}) \times (\text{no. of tanks}) \times (\$15/\text{filter})$$

e. Disposal. Unit cost of disposal was calculated by multiplying the total number of tanks/year, i.e., totanks (see 10.c.) by the weight of a tank at the time of regeneration, including rinse water (see 3.f).

$$(\text{UNC\_RCE}/2,000) \times 4,845 \text{ lb/tank} = 3,183 \text{ lb/yr}$$

$$\text{If total wt} < 42,000 \text{ lb, disposal cost} = \text{wt (lb)} \times (\$0.110/\text{lb})$$

$$\text{If total wt} \geq 42,000 \text{ lb, disposal cost} = \text{wt (lb)} \times (\$0.068/\text{lb})$$

f. The cost of water was calculated as follows, based on 200 gallons water for a model 100 scrubber:

$$\text{Cost of water} = 2 \times (\text{scrubber model}) \times (\text{No. of regenerations}) \times (\$0.25/1,000 \text{ gallons H}_2\text{O})$$

g. The cost of electricity was calculated as follows. Assumed one sterilization cycle per day for facilities that were assigned a model 25 or 50 scrubber and 1.6 cycles per day for facilities with larger than or equal to model 100 scrubbers.<sup>43</sup> All facilities were assumed to operate 270 days per year.<sup>43</sup> Amps were calculated as (scrubber model)/[(model)<sup>0.7</sup> × 2.5].<sup>44</sup> Assumed 110-volt electricity.<sup>44</sup>

$$\text{Electricity costs} = (\text{amps}) \times (110) \times (\text{No. cycles/day}) \times (270) \times (\$0.0432/1,000 \text{ kW}\cdot\text{h})^{12}$$

h. Compressed air. The cost of 10 seconds of compressed air per cycle was considered negligible and was not calculated for this cost analysis.

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**APPENDIX D.**  
**CAPITAL COSTS (F.O.B) OF CATALYTIC OXIDIZERS**

TABLE D-1. COST OF EtO ABATOR™ CATALYTIC  
OXIDIZERS (F.O.B.)<sup>1-3</sup>  
(1987 Dollars)

Design flow rate, ft <sup>3</sup> /min	Cost, \$ <sup>a b</sup>
1,000	48,000
3,000	81,000
6,000	112,000
9,000	148,000
12,000	189,000

<sup>a</sup>Costs in 1989 dollars were corrected to 1987 dollars using the Chemical Engineering Plant Cost indices.

<sup>b</sup>Cost of replacement catalyst is \$1,500/cell in 1989 dollars, or approximately \$1,240/cell in 1987 dollars.<sup>2,4,5</sup>

#### References

1. Letter and attachments from Olson, C., Donaldson Company, Inc., to Srebro, S., MRI. March 23, 1989. Capital and operating costs of 1,000 ft<sup>3</sup>/min EtO Abator™ catalytic oxidizer.
2. Telecon. Srebro, S., MRI, with Olson, C., Donaldson Company, Inc. April 4, 1989. Discussion about costs of EtO Abator™.
3. Telecon. Nicholson, R., MRI, with Olson, C., Donaldson, Company, Inc. May 12 and June 13, 1988. Costs of EtO Abators™.
4. Chemical Engineering. Economic Indicators. April 25, 1988. p. 9.
5. Chemical Engineering. Economic Indicators. June 1989. p. 224.

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APPENDIX E.  
MANIFOLDING COSTS

TABLE E-1. MANIFOLDING COSTS FOR A DEDICATED  
GAS/SOLID REACTOR CONTROL UNIT<sup>1,2,3,4,5</sup>

Item	Cost, \$, 1987	Reference
<u>Rear chamber exhaust (RCE) vent to manifold<sup>a</sup></u>		
1. 15 ft 10-in. diameter, 1/8 in. thick carbon steel	210	Gard, p. 4-19
2. 90° elbow, 10-in. diameter	204	Gard, p. 4-22
3. Labor <sup>b</sup>	164	Richardson, 15-9 p. 2
<u>Manifold</u>		
1. 36 ft 41-in. diameter, 1/8 in. thick carbon steel	2,290	Gard, p. 4-19
2. Labor <sup>b</sup>	1,352	Richardson, 15-9 p. 2
<u>Manifold to control unit</u>		
1. 30 ft 24-in. diameter, 1/8 in. thick carbon steel	1,110	Gard, p. 4-19
2. 90° elbow, 24-in. diameter	580	Gard, p. 4-22
3. Tec, 24-in. diameter	192	Gard, p. 4-22
4. Labor <sup>b</sup>	769	Richardson, 15-9 p. 2

<sup>a</sup>Costs to duct RCE vent to manifold were calculated for each sterilizer at a facility. (It was assumed that ductwork costs for one of the sterilizers was included in the control device installation cost.)

<sup>b</sup>Labor costs developed as \$3.51/ft<sup>2</sup> of ductwork.

TABLE E-2. DUCTWORK COSTS OF REAR CHAMBER EXHAUST MANIFOLD  
TO AN AERATION ROOM CONTROL DEVICE<sup>1,2,20,23,45</sup>

Item	Cost, \$, 1987	Reference
<b>Rear chamber exhaust (RCE) ductwork</b>		
A. RCE vent to manifold <sup>a</sup>		
1. 15 ft 10-in. diameter, 1/8 in. thick carbon steel	210	Gard, p. 4-19
2. 90° elbow, 10-in. diameter	204	Gard, p. 4-22
3. Labor <sup>b</sup>	164	Richardson, 15-9, p. 2
B. RCE manifold		
1. 36 ft 4-in. diameter, 1/8 in. thick carbon steel	1,910	Gard, p. 4-19
2. Labor	1,130	Richardson, 15-9, p. 2
C. RCE manifold to aeration ductwork		
1. 40 ft 24-in. diameter, 1/8 in. thick carbon steel	1,480	Gard, p. 4-19
2. 90° elbow, 24-in. diameter	580	Gard, p. 4-22
3. Tee, 24-in. diameter	190	Gard, p. 4-22
4. Labor <sup>b</sup>	989	Richardson, 15-9, p. 2
<b>Aeration room (AR) ductwork</b>		
A. AR unit to manifold <sup>c</sup>		
1. 32 ft 15-in. diameter, 1/8 in. thick carbon steel	710	Gard, p. 4-19
2. 90° elbow, 15-in. diameter	326	Gard, p. 4-22
3. Labor <sup>b</sup>	481	Richardson, 15-9 p. 2
B. AR manifold <sup>c</sup>		
1. 5 ft 41-in. diameter, 1/8 in. thick carbon steel	318	Gard, p. 4-19
2. Labor <sup>b</sup>	187	Richardson, 15-9 p. 2
C. Manifold to control unit		
1. 67 ft 24-in. diameter, 1/8 in. thick carbon steel	2,480	Gard, p. 4-19
2. 90° elbow, 24-in. diameter	1,160	Gard, p. 4-22
three at \$580		
3. Labor <sup>b,d</sup>	2,140	Richardson, 15-9 p. 2

<sup>a</sup>Costs to duct rear chamber exhaust vent emissions to the manifold were calculated for each sterilizer at a facility. (It was assumed that ductwork costs for one sterilizer is included in the control device installation cost.)

<sup>b</sup>Labor costs developed as \$3.51/ft<sup>2</sup> of ductwork.

<sup>c</sup>Labor costs include the cost to concrete core drill (24 in. hole) the aeration room wall at \$784.

**APPENDIX F.**  
**CHEMICAL ENGINEERING COST INDICES**

TABLE F-1. CHEMICAL ENGINEERING COST INDICES

	Cost indices	Conversion factor
Scrubbers	352.2 (1987) <sup>a</sup> 392.1 (1989) <sup>b</sup>	0.90
Chlorine filters	352.2 (1987) <sup>c</sup> 344.1 (1987) <sup>d</sup>	1.02
Chemicals	340.8 (1987) <sup>e</sup> 340.0 (1986) <sup>f</sup>	1.002
Operations and maintenance labor	323.8 (1987) <sup>g</sup> 218.8 (1988) <sup>h</sup>	1.48
Disposal of ethylene glycol and reactant	323.8 (1987) <sup>i</sup> 318.4 (1986) <sup>j</sup>	1.02
Catalytic oxidizer/gas/solid reactor	352.2 (1987) <sup>k</sup> 390.7 (1989) <sup>l</sup>	0.90
Catalytic/reactant replacement	340.8 (1987) <sup>m</sup> 412.0 (1989) <sup>n</sup>	0.83
Ductwork	323.8 (1987) <sup>o</sup> 218.8 (1978) <sup>p</sup>	1.48
Disposal of catalyst/reactant	329.8 (1987) <sup>q</sup> 354.2 (1989) <sup>r</sup>	0.93
Labor for installation of ductwork	323.8 (1987) <sup>s</sup> 322.7 (1984) <sup>t</sup>	1.00

(continued)



TABLE F-1. (continued)

- 
- <sup>a</sup>Reference 22. CE Plant Cost Index, Equipment Machinery, Supports. October 1987 final.
- <sup>b</sup>Reference 24. CE Plant Cost Index, Equipment. September 1989 final.
- <sup>c</sup>Reference 22. Structural Supports and Miscellaneous. October 1987 final.
- <sup>d</sup>Reference 20. Structural Supports and Miscellaneous. February 1986 final.
- <sup>e</sup>Reference 21. Current Business Indicators. October 1987 latest.
- <sup>f</sup>Reference 20. Current Business Indicators. February 1986 previous.
- <sup>g</sup>Reference 22. CE Plant Cost Index, 1987 Annual Index.
- <sup>h</sup>Reference 22. CE Plant Cost Index, 1978 Annual Index.
- <sup>i</sup>Reference 22. CE Plant Cost Index, 1987 Annual Index.
- <sup>j</sup>Reference 22. CE Plant Cost Index, 1986 Annual Index.
- <sup>k</sup>Reference 22. CE Plant Cost Index, Equipment, Machinery, Supports. October 1987 final.
- <sup>l</sup>Reference 23. CE Plant Cost Index. Equipment, March 1989 final.
- <sup>m</sup>Reference 26. Current Business Indicators, Producer Prices, Industrial Chemicals, October 1987 (latest).
- <sup>n</sup>Reference 23. Current Business Indicators, Producer Prices, Industrial Chemicals, March 1989.
- <sup>o</sup>Reference 23. CE Plant Cost Index, 1987 Annual Index.
- <sup>p</sup>Reference 20. CE Plant Cost Index, 1978 Annual Index.
- <sup>q</sup>Reference 22. CE Plant Cost Index, October 1987 final.
- <sup>r</sup>Reference 23. CE Plant Cost Index, March 1989 final.
- <sup>s</sup>Reference 23. CE Plant Cost Index, 1987 Annual Index.
- <sup>t</sup>Reference 23. CE Plant Cost Index, 1984 Annual Index.

APPENDIX G.  
PROGRAMS USED TO PERFORM COST ANALYSES.

```

*-----
* Program Name:  SAFERCE.prg
*
*   Calculates SAFE CELL
*   capital costs, annualized costs,
*   and cost effectiveness for rear
*   chamber exhaust emissions
*-----

```

SET TALK OFF

```

SELECT 1
USE  SAFERCE

```

```

*-----
SELECT 1

```

DO WHILE .NOT. EOF()

\* CE Conversion Factors:

```

A = 352.2/390.7
B = 340.8/412.0
C = 323.8/218.8
D = 323.8/318.4
E = 323.8/322.7

```

MPID = PID

? MPID

```

*-----RCE EMISSION SPLIT

```

\* PERCENT OF EO USE TO RCE = PRCE\*100

PRCE = 0.02

```

*-----FIND NUMBER OF SAFE CELL UNITS

```

STORE 0 TO N1,N3,N6,N9,N12

IF number < 3

N3 = 1

ELSE

N6 = 1

ENDIF

```

*----- CAPITAL COST OF SAFE CELL

```

F3 = exp(log(3)\*0.7)

F6 = exp(log(6)\*0.7)

F9 = exp(log(9)\*0.7)

F12 = exp(log(12)\*0.7)

CFOB = 19000\*(N1+(N3\*F3)+(N6\*F6)+(N9\*F9)+(N12\*F12))

R1 = CFOB\*A

DO ROUND

CFOB = R2

RELEASE R1,R2

```

CINS = 0.30*CFOB
R1 = CINS
DO ROUND
CINS = R2
RELEASE R1,R2

```

```

CFT = 0.10*CFOB
R1 = CFT
DO ROUND
CFT = R2
RELEASE R1,R2

```

\*----- MANIFOLDING COSTS

```

IF NUMBER = 1
  CMAN = 0
  LMAN = 0
ELSE
  CMAN = (NUMBER*280)+2822
  LMAN = (NUMBER*164)+1916
ENDIF

```

```

R1 = CMAN*C + LMAN*E
DO ROUND
CMAN = R2
RELEASE R1,R2

```

\*----- TOTAL CAPITAL COSTS

```

CSTCC = CFOB+CINS+CFT+CMAN
R1 = CSTCC
DO ROUND
CSTCC = R2
RELEASE R1,R2
CCON = CSTCC*0.15
R1 = CCON
DO ROUND
CCON = R2
RELEASE R1,R2
CTCC = CSTCC+CCON
R1 = CTCC
DO ROUND
CTCC = R2
RELEASE R1,R2

```

\*----- ANNUAL COSTS (DIRECT OPERATING COSTS)

\*\*MAINTENANCE LABOR AND PARTS

```

CML = (7.87*52)*((0.25*N1)+(0.33*N3)+(0.42*N6)+(0.5*N9))
R1 = CML*C
DO ROUND
CML = R2
RELEASE R1,R2

```

```

CMP = 0.5*CML
R1 = CMP
DO ROUND
CMP = R2

```

RELEASE R1,R2

\*\*ELECTRICITY

KW = (N1\*1.1)+(N3\*10)+(N6\*40)+(N9\*60)\*0.746  
 CP = 0.0432\*KW\*24\*365  
 R1 = CP  
 DO ROUND  
 CP = R2  
 RELEASE R1,R2

\*\*REPLACEMENT OF REACTANT

FLOW = (N1+(N3\*3)+(N6\*6)+(N9\*9)+(N12\*12))\*1000  
 TOTRCT = FLOW\*4  
 EO18 = 1.5\*(PRCE\*EO\_TOT)  
 IF EO18 <= (0.3\*TOTRCT)  
 LIFE = 1.5  
 ELSE  
 LIFE = (1.5\*0.3\*TOTRCT)/EO18  
 ENDIF

CRFP = 0.1\*exp(log(1.1)\*LIFE)/(exp(log(1.1)\*LIFE)-1)  
 CRCT = TOTRCT\*CRFP

R1 = CRCT\*B  
 DO ROUND  
 CRCT = R2  
 RELEASE R1,R2

LRCT = 8\*7.87\*(FLOW/1000)\*CRFP  
 R1 = LRCT\*C  
 DO ROUND  
 LRCT = R2  
 RELEASE R1,R2

\*\*DISPOSAL OF REACTANT

IF TOTRCT < 5000  
 CDISP = 0.15\*TOTRCT\*1.33  
 ELSE  
 CDISP = 0.12\*TOTRCT\*1.33  
 ENDIF

R1 = CDISP\*D  
 DO ROUND  
 CDISP = R2  
 RELEASE R1,R2

\*----- ANNUAL COSTS (INDIRECT OPERATING COSTS)

\*\*OVERHEAD

COV = 0.6\*(CML+CMP)  
 R1 = COV  
 DO ROUND

COV = R2  
RELEASE R1,R2

\*\*PROPERTY TAX, INSURANCE, AND ADMINISTRATION

CPTIA = 0.04\*CTCC  
R1 = CPTIA  
DO ROUND  
CPTIA = R2  
RELEASE R1,R2

\*\*CAPITAL RECOVERY CHARGES

CCRC = 0.16275\*(CTCC-(CRCT+LRCT+CMAN))+0.1175\*CMAN  
R1 = CCRC  
DO ROUND  
CCRC = R2  
RELEASE R1,R2

\*\*\*\*\*TOTAL ANNUALIZED COSTS

CTAC = CML+CMP+CP+CRCT+LRCT+CDISP+COV+CPTIA+CCRC  
R1 = CTAC  
DO ROUND  
CTAC = R2  
RELEASE R1,R2

\*\*\*\*\*CALCULATE COST EFFECTIVENESS

XRCEBASE = PRCE\*EO\_TOT/2204.6  
XRCECON = 0.01 \* XRCEBASE  
XRCERED = XRCEBASE - XRCECON

CCEFF = CTAC/XRCERED  
R3 = CCEFF  
DO ROUND2  
CCEFF = R4  
RELEASE R3,R4

\*\*\*\*\*REPLACE INTO SAFERCE

REPLACE NUM\_1000 WITH N1  
REPLACE NUM\_3000 WITH N3  
REPLACE NUM\_6000 WITH N6  
REPLACE NUM\_9000 WITH N9  
REPLACE NUM\_12000 WITH N12  
REPLACE SAFE\_FOB WITH CFOB  
REPLACE INSTALL WITH CINS  
REPLACE FR TAX WITH CFT  
REPLACE MAN WITH CMAN  
REPLACE STCC WITH CSTCC  
REPLACE CON WITH CCON  
REPLACE TCC WITH CTCC  
REPLACE LAB\_MAIN WITH CML  
REPLACE PAR\_MAIN WITH CMP  
REPLACE UTIL WITH CP  
REPLACE REACT WITH CRCT  
REPLACE LAB\_RCT WITH LRCT  
REPLACE DISP WITH CDISP

REPLACE OVER WITH COV  
REPLACE PTIA WITH CPTIA  
REPLACE CRC WITH CCRC  
REPLACE TAC WITH CTAC  
REPLACE RCEBASE WITH XRCEBASE  
REPLACE RCECON WITH XRCECON  
REPLACE RCERED WITH XRCERED  
REPLACE CEFF WITH CCEFF

CLEAR MEMORY

SKIP

ENDDO  
CLOSE DATA  
SET TALK ON  
CANCEL

```

*-----
* Program Name:  CATRCE.prg
*
*   Calculates catalytic oxidation
*   capital costs, annualized costs,
*   and cost effectiveness for
*   rear chamber exhaust emissions
*-----

```

SET TALK OFF

```

SELECT 1
USE CATRCE

```

```

*-----
SELECT 1

```

DO WHILE .NOT. EOF()

\* CE Conversion Factors:

\* Catalytic oxidizer:

A = 352.2/390.7

\* Catalyst:

B = 340.8/412.0

\* Labor and ductwork (except labor for ductwork):

C = 323.8/218.8

\* Disposal:

D = 329.8/354.2

\* Labor for ductwork:

E = 323.8/322.7

```

*-----
MPID = PID

```

? MPID

```

*-----RCE EMISSION SPLIT

```

\* PERCENT OF EO USE TO RCE = PRCE\*100

PRCE = 0.02

```

*-----FIND NUMBER OF CATALYTIC OXIDIZERS

```

Store 0 to N1,N3,N6,N9,N12

IF number < 3

N3 = 1

ELSE

N6 = 1

ENDIF

```

*----- CAPITAL COST OF CATALYTIC OXIDIZERS

```

CFOB = (N1\*53000)+(N3\*90000)+(N6\*125000)+(N9\*165000);  
+ (N12\*210000)

R1 = CFOB\*A

DO ROUND

CFOB = R2



RELEASE R1,R2

CINS = 0.15\*CFOB

R1 = CINS

DO ROUND

CINS = R2

RELEASE R1,R2

CFT = 0.10\*CFOB

R1 = CFT

DO ROUND

CFT = R2

RELEASE R1,R2

\*----- MANIFOLDING COSTS

IF NUMBER = 1

CMAN = 0

LMAN = 0

ELSE

CMAN = (NUMBER\*280)+2822

LMAN = (NUMBER\*164)+1916

ENDIF

R1 = CMAN\*C + LMAN\*E

DO ROUND

CMAN = R2

RELEASE R1,R2

\*----- TOTAL CAPITAL COSTS

CSTCC = CFOB+CINS+CFT+CMAN

R1 = CSTCC

DO ROUND

CSTCC = R2

RELEASE R1,R2

CCON = CSTCC\*0.15

R1 = CCON

DO ROUND

CCON = R2

RELEASE R1,R2

CTCC = CSTCC+CCON

R1 = CTCC

DO ROUND

CTCC = R2

RELEASE R1,R2

\*----- ANNUAL COSTS (DIRECT OPERATING COSTS)

\*\*MAINTENANCE LABOR AND PARTS

CML = (7.87\*365)\*((0.25\*N1)+(0.33\*N3)+(0.42\*N6);  
+(0.5\*N9)+(0.58\*N12))

R1 = CML\*C

DO ROUND

CML = R2

RELEASE R1,R2

CMP = (150\*N1)+(200\*N3)+(250\*N6)+(300\*N9)+(350\*N12)

R1 = CMP

DO ROUND

CMP = R2  
RELEASE R1,R2

## \*\*ELECTRICITY

KW = (N1\*80)+(N3\*120)+(N6\*180)+(N9\*230)+(N12\*290)  
CP = 0.0432\*0.46\*KW\*24\*365  
R1 = CP  
DO ROUND  
CP = R2  
RELEASE R1,R2

## \*\*REPLACEMENT OF CATALYST

NCAT = (N1\*4)+(N3\*16)+(N6\*32)+(N9\*48)+(N12\*64)  
CCAT = (1400\*NCAT)\*0.31547  
R1 = CCAT\*B  
DO ROUND  
CCAT = R2  
RELEASE R1,R2

LCAT = (NCAT\*1\*7.87)\*0.31547  
R1 = LCAT\*C  
DO ROUND  
LCAT = R2  
RELEASE R1,R2

## \*\*DISPOSAL OF CATALYST

CDISP = (80\*(90\*NCAT)/400)\*0.25 + (90\*25\*NCAT)/(62.4\*7.35\*4)  
R1 = CDISP\*D  
DO ROUND  
CDISP = R2  
RELEASE R1,R2

## \*----- ANNUAL COSTS (INDIRECT OPERATING COSTS)

### \*\*OVERHEAD

COV = 0.6\*(CML+CMF)  
R1 = COV  
DO ROUND  
COV = R2  
RELEASE R1,R2

### \*\*PROPERTY TAX, INSURANCE, AND ADMINISTRATION

CPTIA = 0.04\*CTCC  
R1 = CPTIA  
DO ROUND  
CPTIA = R2  
RELEASE R1,R2

### \*\*CAPITAL RECOVERY CHARGES

CCRC = 0.16275\*(CTCC-(CCAT+LCAT+CMAN))+0.1175\*CMAN  
R1 = CCRC  
DO ROUND  
CCRC = R2

RELEASE R1,R2

\*\*\*\*\*TOTAL ANNUALIZED COSTS

CTAC = CML+CMP+CP+CCAT+LCAT+CDISP+COV+CPTIA+CCRC  
R1 = CTAC  
DO ROUND  
CTAC = R2  
RELEASE R1,R2

\*\*\*\*\*CALCULATE COST EFFECTIVENESS

XRCEBASE = PRCE\*EO TOT/2204.6  
XRCECON = 0.01 \* XRCEBASE  
XR CERED = XRCEBASE - XRCECON

CCEFF = CTAC/XR CERED  
R3 = CCEFF  
DO ROUND2  
CCEFF = R4  
RELEASE R3,R4

\*\*\*\*\*REPLACE INTO CATRCE

REPLACE NUM\_1000 WITH N1  
REPLACE NUM\_3000 WITH N3  
REPLACE NUM\_6000 WITH N6  
REPLACE NUM\_9000 WITH N9  
REPLACE NUM\_12000 WITH N12  
REPLACE CAT\_FOB WITH CFOB  
REPLACE INSTALL WITH CINS  
REPLACE FR TAX WITH CFT  
REPLACE MAN WITH CMAN  
REPLACE STCC WITH CSTCC  
REPLACE CON WITH CCON  
REPLACE TCC WITH CTCC  
REPLACE LAB\_MAIN WITH CML  
REPLACE PAR\_MAIN WITH CMP  
REPLACE UTIL WITH CP  
REPLACE CAT WITH CCAT  
REPLACE LAB CAT WITH LCAT  
REPLACE DISP WITH CDISP  
REPLACE OVER WITH COV  
REPLACE PTIA WITH CPTIA  
REPLACE CRC WITH CCRC  
REPLACE TAC WITH CTAC  
REPLACE RCEBASE WITH XRCEBASE  
REPLACE RCECON WITH XRCECON  
REPLACE RCERED WITH XR CERED  
REPLACE CEFF WITH CCEFF

CLEAR MEMORY

SKIP

ENDDO  
CLOSE DATA  
SET TALK ON  
CANCEL

```

*-----
* Program Name:  CATMAN.prg
*
*   Calculates catalytic oxidation
*   capital costs, annualized costs,
*   and cost effectiveness for
*   manifolded aeration room and
*   rear chamber exhaust emissions
*-----

```

SET TALK OFF

```

SELECT 1
USE CATMAN

```

```

*-----
SELECT 1

```

DO WHILE .NOT. EOF()

\* CE Conversion Factors:

\* Catalytic oxidizer:

A = 352.2/390.7

\* Catalyst:

B = 340.8/412.0

\* Labor and ductwork (except labor for ductwork):

C = 323.8/218.8

\* Disposal:

D = 329.8/354.2

\* Labor for ductwork:

E = 323.8/322.7

```

*-----
MPID = PID

```

? MPID

A1 = num\_cells

TCAR = cost\_cells

```

*-----MANIFOLDED EMISSION SPLIT

```

\* PERCENT OF EO USE TO AER. ROOM + RCE = PMAN\*100

PMAN = 0.05

```

*-----FIND NUMBER OF CATALYTIC OXIDIZERS

```

DO CATMAN25

```

*----- CAPITAL COST OF CATALYTIC OXIDIZERS

```

CFOB = (N1\*53000)+(N3\*90000)+(N6\*125000)+(N9\*165000);  
+ (N12\*210000)

R1 = CFOB\*A

DO ROUND

CFOB = R2

RELEASE R1,R2

```

CINS = 0.15*CFOB
R1 = CINS
DO ROUND
CINS = R2
RELEASE R1,R2

```

```

CFT = 0.10*CFOB
R1 = CFT
DO ROUND
CFT = R2
RELEASE R1,R2

```

\*----- MANIFOLDING COSTS

```

IF NUMBER = 1
  CMAN = 742 + 2*((A1*917)+2460)
  LMAN = 530 + 2*((A1*665)+2130)
ELSE
  CMAN = (NUMBER*280) + 2811 + 2*((A1*917)+2460)
  LMAN = (NUMBER*164) + 2116 + 2*((A1*665)+2130)
ENDIF
R1 = CMAN*C + LMAN*E
DO ROUND
CMAN = R2
RELEASE R1,R2

```

\*----- TOTAL CAPITAL COSTS

```

CSTCC = TCAR+CFOB+CINS+CFT+CMAN
R1 = CSTCC
DO ROUND
CSTCC = R2
RELEASE R1,R2
CCON = CSTCC*0.15
R1 = CCON
DO ROUND
CCON = R2
RELEASE R1,R2
CTCC = CSTCC+CCON
R1 = CTCC
DO ROUND
CTCC = R2
RELEASE R1,R2

```

\*----- ANNUAL COSTS (DIRECT OPERATING COSTS)

\*\*MAINTENANCE LABOR AND PARTS

```

CML = (7.87*365)*((0.25*N1)+(0.33*N3)+(0.42*N6);
      +(0.5*N9)+(0.58*N12))
R1 = CML*C
DO ROUND
CML = R2
RELEASE R1,R2

```

```

CMP = (150*N1)+(200*N3)+(250*N6)+(300*N9)+(350*N12)
R1 = CMP
DO ROUND
CMP = R2

```

RELEASE R1,R2

**\*\*ELECTRICITY**

$KW = (N1*80) + (N3*120) + (N6*180) + (N9*230) + (N12*290)$

$CP = 0.0432*0.46*KW*24*365$

R1 = CP

DO ROUND

CP = R2

RELEASE R1,R2

**\*\*REPLACEMENT OF CATALYST**

$NCAT = (N1*4) + (N3*16) + (N6*32) + (N9*48) + (N12*64)$

$CCAT = (1400*NCAT)*0.31547$

R1 = CCAT\*B

DO ROUND

CCAT = R2

RELEASE R1,R2

$LCAT = (NCAT*1*7.87)*0.31547$

R1 = LCAT\*C

DO ROUND

LCAT = R2

RELEASE R1,R2

**\*\*DISPOSAL OF CATALYST**

$CDISP = (80*(90*NCAT)/400)*0.25 + (90*25*NCAT)/(62.4*7.35*4)$

R1 = CDISP\*D

DO ROUND

CDISP = R2

RELEASE R1,R2

**\*----- ANNUAL COSTS (INDIRECT OPERATING COSTS)**

**\*\*OVERHEAD**

$COV = 0.6*(CML+CMP)$

R1 = COV

DO ROUND

COV = R2

RELEASE R1,R2

**\*\*PROPERTY TAX, INSURANCE, AND ADMINISTRATION**

$CPTIA = 0.04*CTCC$

R1 = CPTIA

DO ROUND

CPTIA = R2

RELEASE R1,R2

**\*\*CAPITAL RECOVERY CHARGES**

$CCRC = 0.16275*(CTCC-(CCAT+LCAT+CMAN)) + (0.1175*CMAN)$

R1 = CCRC

DO ROUND

CCRC = R2

RELEASE R1,R2

\*\*\*\*\*TOTAL ANNUALIZED COSTS

CTAC = CML+CMP+CP+CCAT+LCAT+CDISP+COV+CPTIA+CCRC  
 R1 = CTAC  
 DO ROUND  
 CTAC = R2  
 RELEASE R1,R2

\*\*\*\*\*CALCULATE COST EFFECTIVENESS

XMANBASE = PMAN\*EO\_TOT/2204.6  
 XMANCON = 0.01 \* XMANBASE  
 XMANRED = XMANBASE - XMANCON

CCEFF = CTAC/XMANRED  
 R3 = CCEFF  
 DO ROUND2  
 CCEFF = R4  
 RELEASE R3,R4

\*\*\*\*\*REPLACE INTO CATMAN

REPLACE NUM\_1000 WITH N1  
 REPLACE NUM\_3000 WITH N3  
 REPLACE NUM\_6000 WITH N6  
 REPLACE NUM\_9000 WITH N9  
 REPLACE NUM\_12000 WITH N12  
 REPLACE CAT\_FOB WITH CFOB  
 REPLACE INSTALL WITH CINS  
 REPLACE FR TAX WITH CFT  
 REPLACE MAN WITH CMAN  
 REPLACE STCC WITH CSTCC  
 REPLACE CON WITH CCON  
 REPLACE TCC WITH CTCC  
 REPLACE LAB\_MAIN WITH CML  
 REPLACE PAR\_MAIN WITH CMP  
 REPLACE UTIL WITH CP  
 REPLACE CAT WITH CCAT  
 REPLACE LAB\_CAT WITH LCAT  
 REPLACE DISP WITH CDISP  
 REPLACE OVER WITH COV  
 REPLACE PTIA WITH CPTIA  
 REPLACE CRC WITH CCRC  
 REPLACE TAC WITH CTAC  
 REPLACE MANBASE WITH XMANBASE  
 REPLACE MANCON WITH XMANCON  
 REPLACE MANRED WITH XMANRED  
 REPLACE CEFF WITH CCEFF

CLEAR MEMORY

SKIP

ENDDO  
 CLOSE DATA  
 SET TALK ON

```
*****  
*   Program Name:  CATMAN25.prg  
*   Subroutine to CATMAN.prg  
*****
```

```
PUBLIC N1,N3,N6,N9,N12  
STORE 0 TO N1,N3,N6,N9,N12
```

```
A1=NUM_CELLS  
M1=ROUND(A1/24,0)  
M2=M1*12
```

```
DO CASE
```

```
    CASE A1-M2 <= 12 .AND. A1-M2 > 0  
        N3 = M1
```

```
    CASE A1-M2 > 12  
        N3 = M1+1
```

```
    OTHERWISE  
        N3 = M1-1
```

```
ENDCASE
```

```
    IF NUMBER<3  
        N6 = 1  
        N9 = 0
```

```
    ELSE  
        N6 = 0  
        N9 = 1
```

```
    ENDIF
```

```
RETURN
```



```

*-----
* Program Name:  SAFEMAN.prg
*
*   Calculates SAFE CELL
*   capital costs, annualized costs,
*   and cost effectiveness for aeration
*   rooms and rear chamber exhaust
*-----

```

SET TALK OFF

```

SELECT 1
USE SAFEMAN

```

```

*-----
SELECT 1

```

DO WHILE .NOT. EOF()

\* CE Conversion Factors:

```

A = 352.2/390.7
B = 340.8/412.0
C = 323.8/218.8
D = 323.8/318.4
E = 323.8/322.7

```

MPID = PID

? MPID

```

A1 = num_cells
TCAR = cost_cells

```

```

*-----MANIFOLDED EMISSION SPLIT

```

\* PERCENT OF EO USE TO AER. ROOM + RCE = PMAN\*100

PMAN = 0.05

```

*-----FIND NUMBER OF SAFE CELL UNITS

```

DO CATMAN25

```

*----- CAPITAL COST OF SAFE CELL

```

```

F3 = exp(log(3)*0.7)
F6 = exp(log(6)*0.7)
F9 = exp(log(9)*0.7)
F12 = exp(log(12)*0.7)

```

CFOB = 19000\*(N1+(N3\*F3)+(N6\*F6)+(N9\*F9)+(N12\*F12))

R1 = CFOB\*A

DO ROUND

CFOB = R2

RELEASE R1,R2

CINS = 0.30\*CFOB

```

R1 = CINS
DO ROUND
CINS = R2
RELEASE R1,R2

```

```

CFT = 0.10*CFOB
R1 = CFT
DO ROUND
CFT = R2
RELEASE R1,R2

```

\*----- MANIFOLDING COSTS

```

IF NUMBER = 1
  CMAN = 743 + (A1*917) + 2460
  LMAN = 530 + (A1*665) + 2130
ELSE
  CMAN = (NUMBER*280) + 2811 + (A1*917) + 2460
  LMAN = (NUMBER*164) + 2116 + (A1*665) + 2130
ENDIF

```

```

R1 = CMAN*C + LMAN*E
DO ROUND
CMAN = R2
RELEASE R1,R2

```

\*----- TOTAL CAPITAL COSTS

```

CSTCC = TCAR+CFOB+CINS+CFT+CMAN
R1 = CSTCC
DO ROUND
CSTCC = R2
RELEASE R1,R2
CCON = CSTCC*0.15
R1 = CCON
DO ROUND
CCON = R2
RELEASE R1,R2
CTCC = CSTCC+CCON
R1 = CTCC
DO ROUND
CTCC = R2
RELEASE R1,R2

```

\*----- ANNUAL COSTS (DIRECT OPERATING COSTS)

\*\*MAINTENANCE LABOR AND PARTS

```

CML = (7.87*52)*((0.25*N1)+(0.33*N3)+(0.42*N6)+(0.50*N9))
R1 = CML*C
DO ROUND
CML = R2
RELEASE R1,R2

```

```

CMP = 0.5*CML
R1 = CMP
DO ROUND
CMP = R2
RELEASE R1,R2

```

# \*\*ELECTRICITY

```
KW = (N1*1.1)+(N3*10)+(N6*40)+(N9*60)*0.746
CP = 0.0432*KW*24*365
R1 = CP
DO ROUND
CP = R2
RELEASE R1,R2
```

# \*\*REPLACEMENT OF REACTANT

```
FLOW = (N1+(N3*3)+(N6*6)+(N9*9)+(N12*12))*1000
TOTRCT = FLOW*4
EO18 = 1.5*(PMAN*EO_TOT)

IF EO18 <= (0.3*TOTRCT)
  LIFE = 1.5
ELSE
  LIFE = (1.5*0.3*TOTRCT)/EO18
ENDIF

CRFP = 0.1*exp(log(1.1)*LIFE)/(exp(log(1.1)*LIFE)-1)
CRCT = TOTRCT*CRFP

R1 = CRCT*B
DO ROUND
CRCT = R2
RELEASE R1,R2

LRCT = 8*7.87*(FLOW/1000)*CRFP
R1 = LRCT*C
DO ROUND
LRCT = R2
RELEASE R1,R2
```

# \*\*DISPOSAL OF REACTANT

```
IF TOTRCT < 5000
  CDISP = 0.15*TOTRCT*1.33
ELSE
  CDISP = 0.12*TOTRCT*1.33
ENDIF

R1 = CDISP*D
DO ROUND
CDISP = R2
RELEASE R1,R2
```

\*----- ANNUAL COSTS (INDIRECT OPERATING COSTS)

# \*\*OVERHEAD

```
COV = 0.6*(CML+CMP)
R1 = COV
DO ROUND
COV = R2
RELEASE R1,R2
```

\*\*PROPERTY TAX, INSURANCE, AND ADMINISTRATION

CPTIA = 0.04\*CTCC  
 R1 = CPTIA  
 DO ROUND  
 CPTIA = R2  
 RELEASE R1,R2

\*\*CAPITAL RECOVERY CHARGES

CCRC = 0.16275\*(CTCC-(CRCT+LRCT+CMAN))+0.1175\*CMAN  
 R1 = CCRC  
 DO ROUND  
 CCRC = R2  
 RELEASE R1,R2

\*\*\*\*\*TOTAL ANNUALIZED COSTS

CTAC = CML+CMP+CP+CRCT+LRCT+CDISP+COV+CPTIA+CCRC  
 R1 = CTAC  
 DO ROUND  
 CTAC = R2  
 RELEASE R1,R2

\*\*\*\*\*CALCULATE COST EFFECTIVENESS

XMANBASE = PMAN\*EO\_TOT/2204.6  
 XMANCON = 0.01 \* XMANBASE  
 XMANRED = XMANBASE - XMANCON

CCEFF = CTAC/XMANRED  
 R3 = CCEFF  
 DO ROUND2  
 CCEFF = R4  
 RELEASE R3,R4

\*\*\*\*\*REPLACE INTO SAFEMAN

REPLACE NUM\_1000 WITH N1  
 REPLACE NUM\_3000 WITH N3  
 REPLACE NUM\_6000 WITH N6  
 REPLACE NUM\_9000 WITH N9  
 REPLACE NUM\_12000 WITH N12  
 REPLACE SAFE\_FOB WITH CFOB  
 REPLACE INSTALL WITH CINS  
 REPLACE FR\_TAX WITH CFT  
 REPLACE MAN\_ WITH CMAN  
 REPLACE STCC WITH CSTCC  
 REPLACE CON WITH CCON  
 REPLACE TCC WITH CTCC  
 REPLACE LAB\_MAIN WITH CML  
 REPLACE PAR\_MAIN WITH CMP  
 REPLACE UTIL\_ WITH CP  
 REPLACE REACT WITH CRCT  
 REPLACE LAB\_RCT WITH LRCT  
 REPLACE DISP\_ WITH CDISP  
 REPLACE OVER WITH COV  
 REPLACE PTIA WITH CPTIA

REPLACE CRC WITH CCRC  
REPLACE TAC WITH CTAC  
REPLACE MANBASE WITH XMANBASE  
REPLACE MANCON WITH XMANCON  
REPLACE MANRED WITH XMANRED  
REPLACE CEFF WITH CCEFF

CLEAR MEMORY

SKIP

ENDDO  
CLOSE DATA  
SET TALK ON

\*\*\*\*\*

\* Program Name: ROUND

\*\*\*\*\*

PUBLIC R2

DO CASE

CASE R1 <= 1000

R2 = R1

CASE R1 > 1000 .and. R1 <= 10000

R2 = ROUND(R1,-1)

CASE R1 > 10000 .and. R1 <= 100000

R2 = ROUND(R1,-2)

CASE R1 > 100000 .and. R1 <= 1000000

R2 = ROUND(R1,-3)

CASE R1 > 1000000 .and. R1 <= 10000000

R2 = ROUND(R1,-4)

CASE R1 > 10000000 .and. R1 <= 100000000

R2 = ROUND(R1,-5)

CASE R1 > 100000000 .and. R1 <= 1000000000

R2 = ROUND(R1,-6)

CASE R1 > 1000000000 .and. R1 <= 10000000000

R2 = ROUND(R1,-7)

CASE R1 > 10000000000

R2 = ROUND(R1,-8)

ENDCASE

RETURN

\*\*\*\*\*

\* Program Name: ROUND2

\*\*\*\*\*

PUBLIC R4

DO CASE

CASE R3 < 1000

R4 = ROUND(R3,-1)

CASE R3 > 1000 .and. R3 <= 10000

R4 = ROUND(R3,-2)

CASE R3 > 10000 .and. R3 <= 100000

R4 = ROUND(R3,-3)

CASE R3 > 100000 .and. R3 <= 1000000

R4 = ROUND(R3,-4)

CASE R3 > 1000000 .and. R3 <= 10000000

R4 = ROUND(R3,-5)

CASE R3 > 10000000 .and. R3 <= 100000000

R4 = ROUND(R3,-6)

CASE R3 > 100000000 .and. R3 <= 1000000000

R4 = ROUND(R3,-7)

CASE R3 > 1000000000

R4 = ROUND(R3,-8)

ENDCASE

RETURN

```

*-----
*Program Name: RCECOST
*
*   Calculates capital costs of controlling
*   rear chamber exhaust emissions with a scrubber
*-----
*   Files Used:
*           SIZERCE (1)
*           CAP_RCE (2)
*-----Initialize
PUBLIC MSIZE, MMODEL, MTANKS, MCONCAP, MSCR, MEPV
PUBLIC A,B,C,D,E,F,G,H,I
SET TALK OFF
SELECT 1
USE SIZERCE
SELECT 2
USE CRCE
ZAP

SELECT 1

*
*-----
*   CE Indices conversion factors:
A = 332.3/319.2
B = 433.0/418.6
C = 401.1/377.1
D = 352.2/344.1
E = 340.8/340.0
F = 323.8/218.8
G = 401.1/382.9
H = 352.2/392.1
I = 323.8/318.4
J = 323.8/322.7
*-----Initialize variables
*   % EO USE EMITTED TO RCE = PE * 100
PE = 0.02

*   CONTROL DEVICE EFFICIENCY = CD * 100
CD = 0.98
*-----

DO WHILE .not. eof()

    mpid = pid
    msize = size_tot
    muncrce = eo_tot*PE
    madd = add
    mmgemis = mg_emisfac
    mneshap = (1-CD)*muncrce/2204.6
    mreduce = (muncrce/2204.6) - mneshap

*-----Exclude all aeration rooms smaller than 250 ft3

    IF size_tot<=250
        SKIP
    ELSE

*-----Find scrubber model and cost

```



```

IF number > 2
  mmodel = 100
  mtanks = 1
  mconcap = 2000
  mscr = 50000 * H
  mepv = 0

```

```

ELSE
  mmodel = 50
  mtanks = 0.5
  mconcap = 1000
  mscr = 30780 * H
  mepv = 0
ENDIF

```

\*-----Round scrubber costs

```

R1 = mscr
DO ROUND
mscr = R2
RELEASE R1,R2

```

\*-----Calculate capital costs

```

IF mtanks < 1 .and. mtanks > 0
  mclfh = 41.50
  mclfin = 20

```

```

ELSE
  mclfh = 41.50 * mtanks
  mclfin = 20 * mtanks
ENDIF

```

```

mpect = mscr + mepv + mclfh
R1 = mpect
DO ROUND
mpect = R2
RELEASE R1,R2

```

```

mt5per = 0.05 * mpect
R1 = mt5per
DO ROUND
mt5per = R2
RELEASE R1,R2

```

```

mf5per = ROUND((0.05 * mpect), -1)
R1 = mf5per
DO ROUND
mf5per = R2
RELEASE R1,R2

```

\*-----Manifolding costs

```

IF number = 1
  cman = 0
  lman = 0
ELSE
  cman = (number*280)+2822
  lman = (number*164)+1916
ENDIF
R1 = cman*F + lman*J
DO ROUND
mman = R2
RELEASE R1,R2

```

\*-----Calculate total capital

```

mtcc = (mpect + mt5per + mf5per) * 2.2 + mman

```

```

R1 = mtcc
DO ROUND
mtcc = R2
RELEASE R1,R2

```

\*-----Replace into CAP\_RCE

Select 2.

APPEND BLANK

```

REPLACE pid WITH mpid
REPLACE size_tot WITH msize
REPLACE model WITH mmodel
REPLACE concap WITH mconcap
REPLACE scr WITH mscr
REPLACE epv WITH mepv
REPLACE clfh WITH mclfh
REPLACE pect WITH mpect
REPLACE clfin WITH mclfin
REPLACE t5per WITH mt5per
REPLACE f5per WITH mf5per
REPLACE man WITH mman
REPLACE tcc WITH mtcc
REPLACE unc_rce WITH muncrce
REPLACE mg_uncfac WITH muncrce/2204.6
REPLACE mg_emisfac WITH mmgemis
REPLACE neshap_rce WITH mneshap
REPLACE red_rce WITH mreduce

```

\*-----

Select 1

SKIP

xpid = pid

? "OLD, NEW:", mpid, xpid

RELEASE ALL LIKE m\*

RELEASE ALL LIKE x\*

ENDIF

ENDDO

CLEAR MEMORY

SET TALK ON

CLOSE DATABASES

```

*-----
*Program Name:  ANN_RCE.prg
*
*  Caculates annualized costs for control
*    of rear chamber exhaust (scrubber)
*-----
*          Files Used:
*
*                  CAP_RCE (1)
*                  ANN_RCE (2)
*-----Initialize
SET TALK OFF
SELECT 1
USE CRCE
SELECT 2
USE ARCE
ZAP
SELECT 1
*-----
*  CE conversion factors:

  A = 332.3/319.2
  B = 433.0/418.6
  C = 401.1/377.1
  D = 352.2/344.1
  E = 340.8/340.0
  F = 323.8/218.8
  G = 401.1/382.9
  H = 352.2/392.1
  I = 323.8/318.4
*-----

DO WHILE .not. eof()
  mpid = pid
  mmodel = model
  mtanks = mmodel/100
  mman = man
  mconcap = mtanks * 2000
  mtcc = tcc
  muncrce = unc_rce
  mmgemis = mg_emisfac
  mneshap = neshap_rce
  mreduce = red_rce
*-----Calculate annual O&M costs
  IF mmodel = 0
    mregs = 0
    mlab = 0
  ELSE
    mregs = muncrce/mconcap
    mlab = 2154 + (7.87 * 16 * mregs)
    mlab = mlab * F
    R1 = mlab
    DO ROUND
    mlab = R2
    RELEASE R1,R2

  ENDIF
  madrums = muncrce/2000
  macid = madrums * 594 * 0.07
*-----Calculate unit cost of base (NaOH)
  mbdrums = ((muncrce/2000) * 250)/350

```

```

DO CASE
  CASE mbd drums > 9
    mbcost = 0.075
  CASE mbd drums > 2 .and. mbd drums < 9
    mbcost = 0.08
  CASE mbd drums <= 2
    mbcost = 0.11
ENDCASE

```

\*-----End calculation of NaOH unit cost

```

mbase = mbd drums * 700 * mbcost

```

```

ENDIF

```

```

IF mtanks < 1

```

```

  mclf = mregs * 15

```

```

ELSE

```

```

  mclf = mregs * mtanks * 15

```

```

ENDIF

```

```

R1 = mclf * D

```

```

DO ROUND

```

```

mclf = R2

```

```

RELEASE R1,R2

```

\*-----ROUND material costs

```

R1 = macid * 1.15 * E

```

```

DO ROUND

```

```

macid = R2

```

```

RELEASE R1,R2

```

```

R1 = mbase * 1.15 * E

```

```

DO ROUND

```

```

mbase = R2

```

```

RELEASE R1,R2

```

```

mmt5 = 0.05 * (macid + mbase + mclf)

```

```

R1 = mmt5

```

```

DO ROUND

```

```

mmt5 = R2

```

```

RELEASE R1,R2

```

```

mmf5 = 0.05 * (macid + mbase + mclf)

```

```

R1 = mmf5

```

```

DO ROUND

```

```

mmf5 = R2

```

```

RELEASE R1,R2

```

\*-----Calculate disposal cost

```

mwt = (muncrce/2000) * 4845

```

```

DO CASE

```

```

  CASE mwt < 42000

```

```

    mdisp = mwt * 0.108

```

```

  CASE mwt >= 42000

```

```

    mdisp = mwt * 0.067

```

```

ENDCASE

```

```

R1 = mdisp * I

```

```

DO ROUND

```

```

mdisp = R2

```

```

RELEASE R1,R2

```

\*-----Calculate utility costs

## DO UTIL\_STER

\*-----Calculate indirect O&M costs

```
mover = 0.6 * mlab
R1 = mover
DO ROUND
mover = R2
RELEASE R1,R2
```

```
mptia = 0.04 * mtcc
R1 = mptia
DO ROUND
mptia = R2
RELEASE R1,R2
```

```
mcrc = 0.16275 * mtcc
R1 = mcrc
DO ROUND
mcrc = R2
RELEASE R1,R2
```

\*-----Calculate total annualized cost

```
mtac = mlab + macid + mbase + mclf + mmt5 + mmf5;
      + mdisp + mwater + melec + mover + mptia + mcrc
R1 = mtac
DO ROUND
mtac = R2
RELEASE R1,R2
```

\*-----Calculate cost effectiveness

```
mceff = mtac/mreduce
R3 = mceff
DO ROUND2
mceff = R4
RELEASE R3,R4
```

\*-----REPLACE into ANN\_RCE

Select 2

## APPEND BLANK

```
REPLACE pid WITH mpid
REPLACE model WITH mmodel
REPLACE concap WITH mconcap
REPLACE unc_rce WITH muncrce
REPLACE regs WITH mregs
REPLACE lab WITH mlab
REPLACE acid WITH macid
REPLACE base WITH mbase
REPLACE clf WITH mclf
REPLACE mt5 WITH mmt5
REPLACE mf5 WITH mmf5
REPLACE disp WITH mdisp
REPLACE water WITH mwater
REPLACE elec WITH melec
REPLACE over WITH mover
REPLACE ptia WITH mptia
REPLACE crc WITH mcrc
REPLACE tac WITH mtac
REPLACE neshap_rce WITH mneshap
REPLACE red_rce WITH mreduce
REPLACE ceff WITH mceff
REPLACE per_disp WITH (disp/tac)*100
```

\*-----

Select 1

SKIP

? "PID:", mpid

RELEASE ALL LIKE m\*

ENDDO

CLEAR MEMORY

CLOSE DATABASES

SET TALK ON

```
-----  
*Program Name:  UTIL_STER.prg  
* Subroutine to ANN_STER.prg  
*  Caculates utility costs for control  
*    of vent and drain emissions  
*-----
```

```
PUBLIC Mwater, MELEC
```

```
*-----Calculate utility costs
```

```
mwater = 2 * mmodel * mregs * (0.25/1000)  
R1 = mwater  
DO ROUND  
mwater = R2  
RELEASE R1,R2
```

```
J = (mmodel/100)  
K = LOG(J)  
L = 0.7 * K  
M = EXP(L)
```

```
mamp = mmodel/(M*2.5)
```

```
IF mmodel < 100  
  melec = (mamp*110)*(1*0.5*270)*(0.0432/1000)  
ELSE  
  melec = (mamp*110)*(1.6*1*270)*(0.0432/1000)  
ENDIF
```

```
R1 = melec  
DO ROUND  
melec = R2  
RELEASE R1,R2
```

```
RETURN
```

APPENDIX H.

DATA BASES USED TO PERFORM COST ANALYSES.





**FACSIMILE  
CORRESPONDENCE**

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**DATE:** June 15, 1998

**TO:** David Markwordt  
US EPA

**FROM:** Kathleen Steilen - Director  
Environmental, Health & Safety  
Griffith Micro Science  
972-519-9217

**FAX #:** 919-541-0942

**FAX #:** 972-758-0234

**SUBJECT:** Correction to Backvent Emission Calculations

Total Number of Pages (including cover page): 3.

---

David:

Attached are some corrections to the backvent emission calculations. I apologize for any inconvenience that this error may have caused. I also want to thank you for such careful review of estimation calculations. These calculations had been reviewed carefully by several people and no one discovered this mistake.

Please call with any additional questions!

Kathy



2001 SPRING ROAD, SUITE 500 OAK BROOK, ILLINOIS USA 60521-1887 (630) 571-1280 FAX: (630) 571-1245

June 15, 1998

Mr. David Markwordt (via FACSIMILE)  
Policy, Planning and Standards Division (MD13)  
Office of Air Quality Planning and Standards  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711

**Subject: Correction to Information on Typical Backvent Emissions Estimates**

Dear Mr. Markwordt:

As we discussed last week, the calculations presented for the backvent estimates needed to be updated to better reflect our current sterilization operations. This letter and attached table explain the revisions to the previous emissions estimate. These revisions increase our estimate of emissions from the backvents (chamber exhaust vents) from 0.2 to 0.25 percent of the total EtO emissions from the sterilization process.

Table 1 (attached) contains revised backvent emission calculations. The numbers presented in my June 9<sup>th</sup> letter used a typical gas charge of 140 pounds EtO for 13-pallet chambers. This gas charge is actually more typical for our larger chambers. The typical EtO gas range for 13-pallet chambers is 95 to 105 pounds EtO. (The maximum EtO charge is about 120 pounds.) Using 100 pounds as the average EtO charge, backvent emissions can be estimated as 0.25 percent of the total EtO emissions from the sterilization process.

It is important to emphasize again that these backvent emission estimates will vary greatly depending on the sterilization cycle. We are trying put together a more dynamic look at the backvent concentrations for you for various types of Griffith Micro Science's sterilization cycles. I am also encouraging other sterilization manufacturers to gather similar information for you. Hopefully, this information will be documented before our meeting with you on June 25, 1998.

If you have any further questions or need any more information, please call me at 972-519-9217.

Sincerely,

Kathleen A. Steilen, P.E.  
Environmental, Health & Safety Director

**Attachments: Table 1 - Revised Chamber Backvent Calculations**

cc: Frank Lange - Griffith  
Jim Legg - Griffith Laboratories  
Joe Hadley - EOSA Attorney

**Table 1**

**REVISED CHAMBER BACKVENT CALCULATIONS**

**Purpose:** Determine the approximate percentage of the total EtO usage that is vented in the chamber back vents.

**Assumptions:**

1. The backvent emissions can be estimated using The Ideal Gas Law.
2. The concentration in the chamber when the door is opened is about 20% LEL (or 6000 ppm).  
(confirmed with plant data)
3. The chamber is full with product after one of our most popular cycles.

**Calculations:**

Volume of 1 mole =  $V = nRT/P$   
(at 1 atm & 130 F)  
 $V = (1 \text{ mole}) * (0.08205 \text{ L atm/mol K}) * (327.6 \text{ K}) / 1 \text{ atm}$   
 $V = 26.88 \text{ L}$   
 $m/V = 44.05 \text{ grams (MW of EtO)} / 26.88 \text{ L}$   
 $m/V = 1.64 \text{ g/L}$

With 20% LEL (or 6000 ppm) in backvent:

$m/V = (6000 / 1,000,000) * (1.64 \text{ g/L})$   
 $m/V = 0.00984 \text{ g/L}$

Chamber volume for 13 pallet chamber is about 1350 ft<sup>3</sup>:

$V = 1350 \text{ ft}^3 * (28.32 \text{ L/ft}^3)$   
 $V = 38232 \text{ L}$

About 70% of the actual chamber volume is occupied by product and not available for evacuation by backvent:

Available Volume =  $0.30 * 38232 \text{ L} = 11470 \text{ L}$   
 $\text{mass/chamber} = (0.00984 \text{ g/L}) * (11470 \text{ L}) / (453.6 \text{ g/lb})$   
 $\underline{0.25 \text{ lb/chamber}} \quad (\text{per each cycle})$

Therefore, there is a total of 0.25 lb EtO available to be evacuated by the backvent.

For 13-pallet chambers, the average gas charge is about 95 to 105 pounds of EtO.  
(For 13-pallet chambers, the maximum gas charge is 120 pounds of EtO.)

Backvent % of EtO charge =  $(\text{mass of EtO in backvent}) / (\text{Average Total EtO charge to chamber})$   
Backvent % =  $(0.25 \text{ lb/chamber}) / (100 \text{ lb/chamber})$

Backvent % = 0.00250  
or 0.250 %